ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF
ECONOMIC GEOLOGISTS

VOL. 47 DECEMBER, 1952 NO. 8

AUTORADIOGRAPHIC STUDY OF MARINE SHALES.[1]

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ABSTRACT.

The autoradiographic study of several marine shales was undertaken in support of previous research, that was concerned with the influence of radioactivity on the transformation of certain organic constituents of marine shales into petroleum hydrocarbons. It was the purpose of the investigation to determine the location of the naturally-occurring radioactive elements, the alpha-particle-emitting members of the uranium and thorium series, with respect to the organic and inorganic constituents of the shales.

This was accomplished by recording the ionizations or tracks of alpha-particles produced in the shales on sensitized nuclear emulsions, which were placed in direct contact with the individual rock sections. Several methods of exposing and analyzing the nuclear emulsions were developed and utilized in order to overcome the limitations resulting from the presence of opaque and fine-grained materials in the shales.

Included in the results of the investigation are discussions of the sources of radioactivity occurring in the individual shales and a tabulation

[1] This paper is a contribution from American Petroleum Institute Research Project 43C located at the Massachusetts Institute of Technology: W. L. Whitehead, Director; Clark Goodman, Physical Director.

of the radioactivity concentrations associated with the organic and inorganic phases. The results for the shales investigated indicate that the inorganic constituents are, on the average, about 72 percent more radioactive than the organic matter.

INTRODUCTION.

INVESTIGATIONS carried out by American Petroleum Institute Research Project 43C during the past nine years have demonstrated that the alpha-particle from naturally-occurring radioactive elements may be instrumental in transforming certain organic constituents of marine shales into petroleum hydrocarbons. Since the range of an alpha-particle in mineral matter is very short (20 to 50 microns in quartz), it is essential that there be a close association between the radioactive element and the organic material that must be decomposed to yield hydrocarbons. It has been suggested in the past that the radioactive elements in marine shales might be present in the form of organo-metallic precipitates, or might have been precipitated as adsorbates on the surfaces of minerals or other inorganic substances of colloidal size. It was the purpose of this investigation to determine the location of the radioactive elements, uranium and thorium and their daughter products, in marine shales with respect to the organic and inorganic constituents of the shales. These studies were carried out by recording the ionizations or tracks of the alpha-particles produced in the shale, on sensitized photographic emulsions placed in contact with the material being studied.

The average energy of the alpha-particles emitted by uranium is about 5.3 Mev and each particle has a range of approximately 23 microns in a silver bromide emulsion. During its traverse, the alpha-particle dissipates about 0.23 Mev per micron, which is a sufficient energy concentration to cause localized ionization in the emulsion. The energy of the trajectory may be likened to that of a photon of light which is capable of decomposing the halide in the emulsion of any standard photographic film. Wherever an alpha-particle, that is emitted by a radioactive constituent within the shale, intercepts the plane of the emulsion, its energy is adsorbed by the halide grains, and the linear paths of the radiation are recorded. Following the development of the emulsion, the resultant tracks appear as linear aggregates of reduced silver grains which can be followed microscopically in depth. Thus, by a study of the tracks recorded in nuclear emulsions, it is possible to trace the origin of the trajectory and locate the source of the radioactive elements in the rock. The grain size of the shales varies from about one to several hundred microns. Since the tracks of the alpha-particles vary in size from a few tenths of a micron to a few microns, the ratio of track size to grain size is approximately 1:10. Assuming that the method of correlating the emulsion with the shale is sufficiently precise, it is possible on the basis of this ratio, to assign each recorded alpha-particle to its source.

METHODS OF STUDY.

There are several methods of approach to the study of the source of the radioactivity in marine shales by means of autoradiography. Attempts have

been made to utilize all of these methods in order to overcome the specific difficulties arising from the opaque nature of some of the constituents of the shales and the fact that the tracks must be magnified considerably more than the individual rock sections. The lack of transparency resulting from the presence of dense organic residues and mineral sulfides in the shales, hampers the investigation to the extent that the tracks cannot be viewed directly through the source of the radiation in the rock section. In the ideal case, thin sections of granites, for example, which are highly transparent, can be coated with a thin layer of the nuclear emulsion, which remains in contact with the section during the exposure, development, and microscopic examination. By means of direct illumination, the alpha-particle tracks can be observed through the source of the activity at magnifications of 300 × or more. This method was used to study shales that contained transparent material. The following procedures were adopted in order to study the problem adequately, and to afford suitable checks for the determinations.

Technique for Coarse Structures.

Core samples of the individual shales were cut perpendicular to the bedding laminae to give sections measuring about 3 in. × 3 in. × ¼ in. Wherever possible an attempt was made to expose unusually thick layers, fossils, or other mineralized structures to the photographic emulsions. The emulsion on a 4 in. × 5 in. glass plate was clamped to the mounted rock section and the outline and details of the rock section were traced onto the glass surface of the nuclear track plate with india ink. Following exposure for one month or longer, the plate was removed, developed, and assayed for alpha-particle tracks. This method of relating the track density to the inked pattern of the surface constituents of the rock was of value only when the structures were larger than 2 or 3 mm.

Technique for Fine Structures.

Opaque Sections.—Representative thin sections of the individual shales were prepared by first impregnating the rock sections with glycol phthalate and then cementing them to 1 in. × 3 in. precision-cut glass slides. Each slide was then ground separately using a series of abrasives on fresh glass plates to avoid contamination. On approaching the desired optical thickness, the section was coated with collodian, which upon drying could be peeled from the rock as a film. A micro-thin layer of the rock section adhered to the film and was removed simultaneously. The process was repeated a number of times, until the resultant surface of the rock was one that had been relatively undisturbed by the grinding action of the abrasives, since such action would probably tend to re-orient radioactive grains. If the investigation had been extended to include a survey of less consolidated shales, or sediments, their constituents could have been incorporated in peels or mixtures made from the emulsion, itself.

The completed thin section was placed face down in an exposure holder (Fig. 1) in contact with a nuclear track plate of similar dimensions. It was necessary to join the two slides against one corner of the holder by two per-

pendicular plungers which pushed against the sides equally, thus compensating for variations in length and width of $\frac{1}{64}$ in. or less. It was also essential to work with highly rectangular slides, since deviations of 0.1° or more from the edge normals would lessen the chance of duplicating the respective positions of the superimposed slides. When the available commercial-type slides did

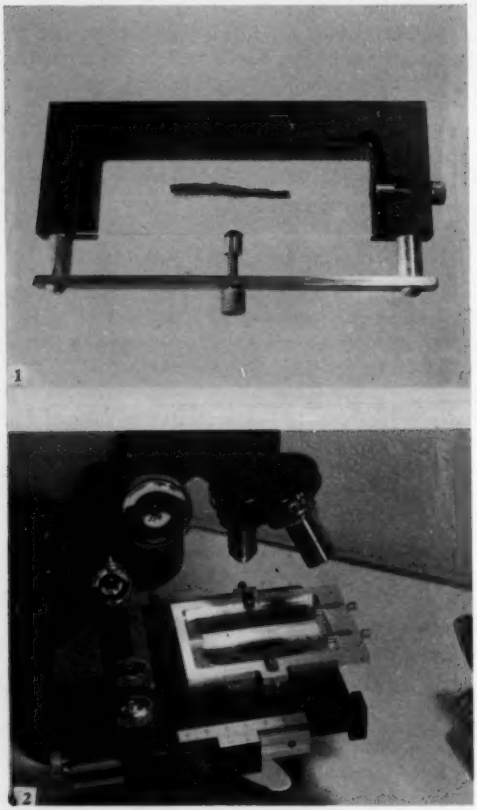

FIG. 1. Exposure holder for nuclear track plate and thin section.
FIG. 2. Twin-type holder for assay of nuclear track plate and corresponding thin section.

not meet this specification, it was necessary to coat precision-cut slides with a layer of the unsupported nuclear emulsion. The most firmly fixed pair of slide corners was subsequently marked, so that the slide pair could be oriented properly in a twin-type holder (Fig. 2) after development of the nuclear track

plate. The method is discussed further in the section dealing with detailed application of the techniques.

Transparent Sections.—When the thin sections of the shales studied were sufficiently transparent, the nuclear emulsion was applied directly to them, without the support of a glass backing. The unsupported emulsions used for this work are manufactured by the Eastman Kodak Company, and are sold under the trade names, "Pellicles" and "Stripping Film." For further details, the reader is referred to the report by L. R. Stieff and T. W. Stern (7). The chief advantage in using the unsupported emulsions lies in the fact that the emulsion remains in constant association with the rock source throughout the investigation, thereby facilitating an exact correlation between the alpha-particle tracks and the source of the radiation. It was necessary to pre-coat the rock sections with a thin layer of gelatin in order to maintain a permanent bond between it and the emulsion and to prevent the constituents in the shales from reacting with the halide of the latter. Using this technique it was also possible to observe the alpha-particle tracks emanating from residual, opaque matter along the peripheries of thin sections of the Swedish Kolm.

Several other useful techniques are described by H. V. Buttlar [2] and F. G. Houtermans, R. Coppens, J. Poole and J. Bremmer, and H. Yagoda (1, 2, 4, 5, and 9, respectively).

Detailed Application of the Techniques.

A Spencer monocular microscope, equipped for use with three objectives, a graduated stage, and bright and dark field condensers, was used in the investigation. The graduated stage of the microscope had a to-and-fro movement of 50 mm and a lateral movement of 75 mm with fixed verniers reading to 0.05 mm. At higher magnifications, where the radius of the field was exceedingly small, it was necessary to increase the accuracy of the readings. A set of gears were attached to the horizontal rack of the graduated stage, in order to facilitate reading the horizontal ordinates to within 0.01 mm. The jaws of the mechanical stage were arranged to grasp by spring recoil 3 in. × 1 in. slides, 3 in. × 4 in. slides, and also the twin-type slide holder.

When a thin section and corresponding nuclear track plate were oriented in the twin-type holder correctly, their once-superimposed corners became mirror images. The nuclear track plate was first surveyed at magnifications of 430 × and 970 ×. The coordinates of areas of a specific track density were recorded and by substitution in the equation designated below,[3] the coordinates of the corresponding point on the rock slide were obtained.

A compilation of data was made for each pair of slides, noting the coordinates of the areas surveyed, the number of alpha-particle tracks in the field, and the nature of the source material. When the section was sufficiently transparent and the unsupported emulsion was employed, the tracks were discernible through the section.

[2] Numbers in parentheses refer to Bibliography at end of paper.

[3] If (x_1, y_1) were the coordinates of a point on the slide at the right of center, and x_c was the abscissa of the center line, the coordinates (x_2, y_2), of the corresponding point on the slide at the left of center were related in the following manner: $y_2 = y_1$ and $x_2 = 2x_c - x_1$.

THEORETICAL CONSIDERATIONS.

The thin sections of the shales used in this work were considered as true thin sources (9), since the thickness of the sections in equivalent air-centimeters was less than the mean path of the alpha-particles in air. The total number of disintegrations per second per cm² of source:

$$D = \frac{2C}{1 - \frac{T}{(R_a - p)}} \frac{1}{sA},$$

where: C—the total number of tracks counted less background.
T—the actual thickness of the section in cm multiplied by the factor R_a/R_s.
R_a—the mean range of alpha-particles in air in cm.
R_s—the mean range of alpha-particles in the source in cm.
s—the exposure time in seconds.
A—the area of the source in cm².
p—the track length in air-cm of minimum discernibility.

The lateral shrinkage of the film is of little consequence (6), but shrinkage in depth, resulting from the removal of the halide during processing, does affect the inclination of the tracks. This effect was not serious owing to the fact that the mean ratio of track size to the grain size of the shale was 1:10.

The background counts consisting of tracks considerably shorter than the extended alpha-particle tracks were obtained from blank plates. When the background count reached a maximum of 10 percent of the total track count, the value of the uncertainty of the count was calculated to lie between 10 and 15 percent. Since the amount of radioactivity in the individual shales varied widely with location, only representative sections were studied.

When the ratio of track size to grain size was greater than 1:10, but less than 1:3, the depth of focus of the microscope was increased to follow the track into the emulsion. The other extremity of the track pointed in the general direction of the source of the activity. The entire method was not applicable to shales for which the ratio of track size to grain size was greater than 1:3, since the means of correlating the nuclear plates with the thin sections was less exact. The correlations obtained in the investigation are statistically accurate to within 5 percent.

DISCUSSION OF SPECIFIC SHALES.

Investigations of the *Swedish Kolm*, which is several thousand times more radioactive than the average marine shale, have indicated that the radioactive elements are associated largely with the inorganic constituents. The inorganic matter, chiefly fine-grained pyrite, phosphate, and carbonate (occasionally salts of uranium), is distributed profusely throughout the organic matrix. Due to the fine-grained nature of the constituents of the shale, it was impossible to assign a definite amount of radioactivity to either the organic or the inorganic constituents. An average activity of 118 alpha counts per minute per cm² was assigned to the coarser aggregates of pyrite, and this activity appeared to be small in comparison with that observed in the individual fine grains of the

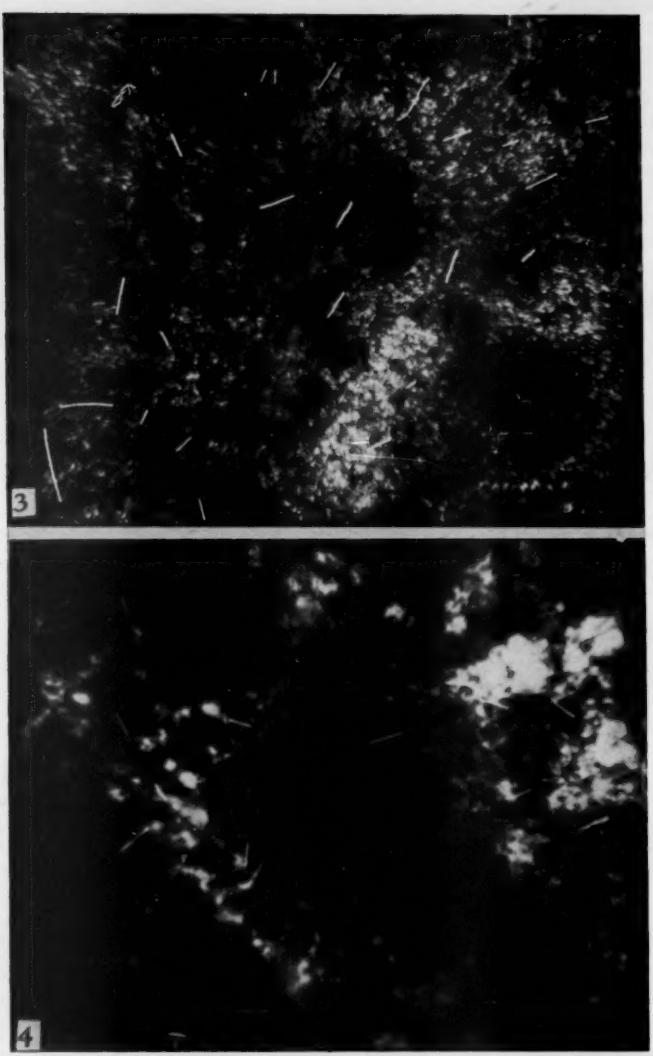

FIG. 3. A phosphatic nodule of the Cherokee shale with superimposed alpha-particle tracks. Magnification 750 ×.

FIG. 4. Phosphatic layers of the Playa del Rey shale and superimposed alpha-particle tracks. Magnification 750 ×.

mineral when taken as a whole. The radioactivity is often concentrated at the surfaces of colloidal grains. Owing to the lack of contrast between the organic material and the alpha-particle tracks, photographs were made of the periphery of thin sections of the Kolm. The tracks could be observed to emanate from small point sources of mineral matter as well as from larger residuals of the organic matter. Although the major part of the radioactivity is derived from the inorganic constituents of the shale, the dissemination of the latter through-

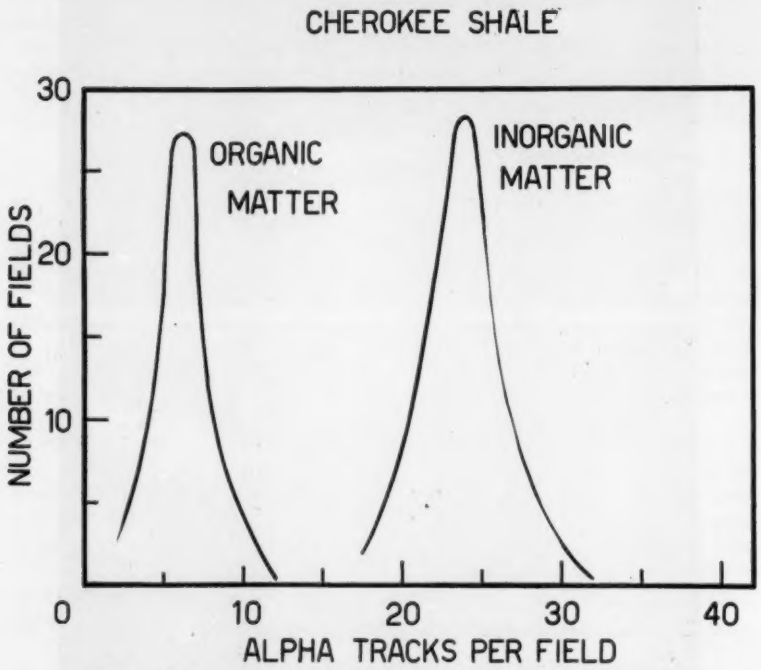

FIG. 5. Cherokee shale alpha-particle track distribution curves.

out the shale might have enabled the radioactivity to be highly effective in transforming the organic constituents.

The *Woodford Shale* of *Texas* is comparable to the Swedish Kolm since it contains an abundance of pyrite that is disseminated throughout the organic matter. It occurs in the shale as minute cubes, elliptical blebs, stringers, and as finely divided masses. The radioactivity is mainly associated with the mineral matter but is also manifest in the organic material. Certain horizons of the Woodford Shale, which are highly fossiliferous and almost devoid of large

grains of the sulfides, exhibit a low activity, further substantiating the fact that there may be a kindred relationship between uranium and the mineral sulfides.

The seasonal white layers and grains of carbonate and phosphate that are distributed throughout the *Woodford Shale* of *Oklahoma* exhibited about 3 times the activity of the surrounding organic material. The radioactive elements are not distributed uniformly throughout these layers, but are localized in certain mineral grains.

The radioactivity of the *Cherokee Shale* is largely associated with the presence of phosphatic nodules, which are distributed more or less randomly throughout the shale. A photograph [4] of phosphatic nodular material, which was deposited about a coprolite nucleus, and superimposed alpha-particle tracks is shown in Figure 3. The organic matter, which surrounds the individual nodules, exhibited only a small fraction of the activity that was associated with the fine-grained nodular material. The sizable differences in the activity of

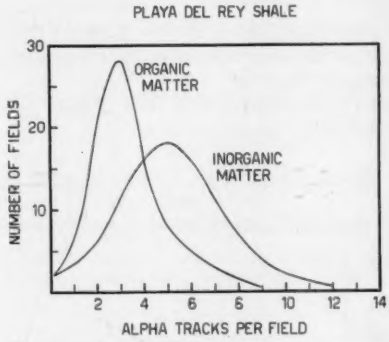

FIG. 6. Playa del Rey shale alpha-particle track distribution curves.

the organic and inorganic constituents of the Cherokee Shales are evident from a study of the track distribution curves for the shale (Fig. 5).

The radioactivity of the *Miocene Nodular Shale* of the *Playa del Rey* field of *California* is more extensively localized in the inorganic nodules and layers than in the organic layers and veinlets. The activity that is associated with a light-colored phosphatic layer is shown in Figure 4. Irrespective of its color or consistency, the organic material exhibits a lesser radioactivity. The track distribution curves for the Playa del Rey Shale (Fig. 6) indicate that there is a wide range for the radioactivity associated with the inorganic constituents. The overlapping of the two curves might be explained by the continuous precipitation of the radioactive elements from the sea onto the sediments com-

[4] The following photographs were obtained by separately photographing a thin section and corresponding nuclear track plate in the twin-type holder. The alpha-particle tracks were rendered white in order to improve the contrast. The photographs were then correlated, using the ocular micrometer as a common reference. The general photographic technique used is that described by I. Tschiderer (8).

prising the shale, at the time of its deposition. The composition and structure of the shale are described by Hoots et al. (3).

RESULTS OF THE INVESTIGATION.

Shale	D-alpha disintegrations/minute/cm²	
	Inorganic material	Organic material
Cherokee, Okla.	3.82	1.16
Miocene Nodular (Playa del Rey)	0.83	0.50
Woodford, Okla.	6.5	2.0
Woodford, Texas	5.80	3.30

The foregoing values of D were obtained for a series of thin sections of each shale using the methods outlined previously.

CONCLUSIONS.

The following conclusions can be drawn from the results listed above:

1. The radioactivity of the shales investigated is associated with both the organic and the inorganic matter.

2. The radioactivity is concentrated to a greater extent in the inorganic matter by a factor of 2.5.

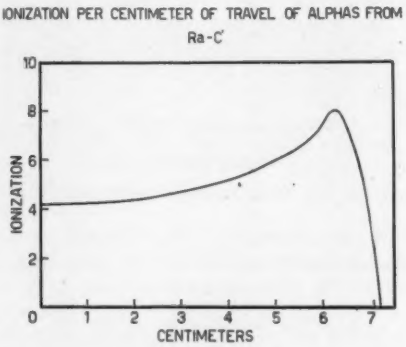

FIG. 7.

Although there is a higher concentration of the radioactive elements in the inorganic material of the shales, alpha-particles that originated close to or at the surfaces of the inorganic matter, by discharging the bulk of their energy in the neighboring organic material, might have been effective in transforming the latter into petroleum hydrocarbons. The variation of the ionization of alpha particles as a function of the distance the particles travel in air is shown in Figure 7. Of limiting consequence is the fact that the range of the alpha-particle in the organic matter is only 0.01 mm longer than in the inorganic material.

ACKNOWLEDGMENT.

The author is very grateful to Professor Walter L. Whitehead and to Dr. Irving A. Breger for their encouraging support and valuable comments during the course of the investigation.

To Mr. John Solo, the author is very much indebted for the construction of the various types of slide holders.

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CAMBRIDGE, MASS.,
Sept. 21, 1952.

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STRUCTURAL LOCALIZATION OF GROUND WATER IN LIMESTONES—"BIG BEND DISTRICT," TEXAS–MEXICO.*

GEORGE A. KIERSCH AND PAUL W. HUGHES.

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ABSTRACT.

Groundwater studies throughout parts of the "Big Bend District" were completed in connection with projected developments along the Rio Grande. Cretaceous limestones are predominant and the major source of ground water. The Edwards limestone, principal aquifer, is overlain by the impervious Kiamichi formation; also favorable structures result in significant production from the younger Georgetown limestone.

The "District" consists of: asymmetrically folded and faulted ranges separated by valleys in the Mexican Highlands; and an ovaloid syncline of low-dipping beds in the Edwards Plateau, which is interrupted by asymmetrical, northwestward-trending flexures. Major springs issue along northwestward-trending faults in the "Highlands" and along northeastward-striking breaks in the "Plateau."

Solutioning, primarily structurally controlled, is a major factor in groundwater movement. Cored borings confirmed this hypothesis and indicated that faults acted both as "barriers" and "avenues." Initial development of solutioning apparently began in middle to late Tertiary time.

Sinkholes as recharge "avenues," particularly in the "Plateau," are associated with crests and troughs of flexures and the intersection of faults, shears, and joints.

Wells located on "highs" and "lows" of flexures yield water from the shallower Georgetown limestone; interconnected openings have apparently developed due to solutioning along fractures, thereby facilitating recharge. In addition, deeper wells yield from the underlying Edwards limestone.

Where the Del Rio clay is absent, the solutioned and altered upper part of the Georgetown limestone is a potential water producer.

Combining calculated permeability factors and geologic data, four generalized reservoir conditions were formulated for the "District."

* Contribution No. 1 (Engineering Geology) from the Department of Geology, University of Arizona.

INTRODUCTION.

THE occurrence of ground water and particularly its structural localization in limestone was studied during geologic investigations [1] of the "Big Bend District." Conclusions presented are based on groundwater data compiled from cored borings and "pumping-in" tests, wells, springs, and stratigraphic studies. Most of the information was collected within the stretch from near Reagan Canyon to Del Rio–Villa Acuna (Fig. 1); certain structural and physiographic features inherent to this section were of prime importance in the selection of dam and reservoir sites therein. Consequently in this part of the "District," and particularly in Mexico, the survey covered a much wider area and in a more detailed manner than throughout the upstream stretch. Conclusions resulted in some significant economic and engineering aspects of groundwater localization in limestone, which are applicable in other areas and may prove of interest.

REGIONAL SETTING.

The "Big Bend District" lies within parts of two physiographic provinces. Upstream from the Consuelo Range front (Fig. 1) is a mountainous region termed the Mexican Highlands while downstream is the westernmost portion of the Edwards Plateau. Structure, both regional and local, strongly controlled the physiographic development, particularly in the Mexican Highlands.

The spectacular topographic relief and northwestward-trending structures of the Mexican Highlands are due to an abundance of asymmetrical folds combined with steep gravity faults. Roughly parallel "monoclinal" folds are common and many vary along their strike from an unbroken monocline to a faulted or step-faulted structure. The effect is the same; one side has been uplifted, the other "thrown." Some "monoclinal" structures suggest horizontal displacement. Gravity fault displacements are measured in hundreds to thousands of feet.

Some ranges are: cuesta-like fault blocks (up to eight miles across); rugged peaks and ridges with intrusive igneous "cores"; plateaus deeply dissected by erosion; and domal uplifts.

The intermontane valleys are down-dropped fault blocks and synclinal basins.

The Edwards Plateau section is an area of a few shear zones and low gentle flexures (Fig. 1). The Rio Grande flows in an ovaloid syncline throughout most of this lower stretch; gentle flexures partially bound the syncline on the east and west. Only the asymmetrical Ague Verde fold trending northwest across the basin (Fig. 1) interrupts the synclinal pattern of the Edwards Plateau section.

[1] A preliminary study of the Rio Grande between Lajitas and Del Rio, Texas, was initiated in late 1948 by the International Boundary and Water Commission, United States and Mexico, under terms of a treaty signed in 1944. Geologically the principal objective was to map a strip 4–12 miles wide athwart the border and to investigate by core drilling and other methods the geologic features of this stretch and all dam and reservoir sites therein. Ideas expressed in this paper are based on data collected by geologic personnel of the Commission, principally during the period 1950–51 when the writers were connected with the survey. L. H. Hendersen, Alpine, Texas, was engineer-in-charge of all activities for the Commission's survey. Thanks are due to Dr. Eldred D. Wilson, Tucson, for suggestions and review of the manuscript.

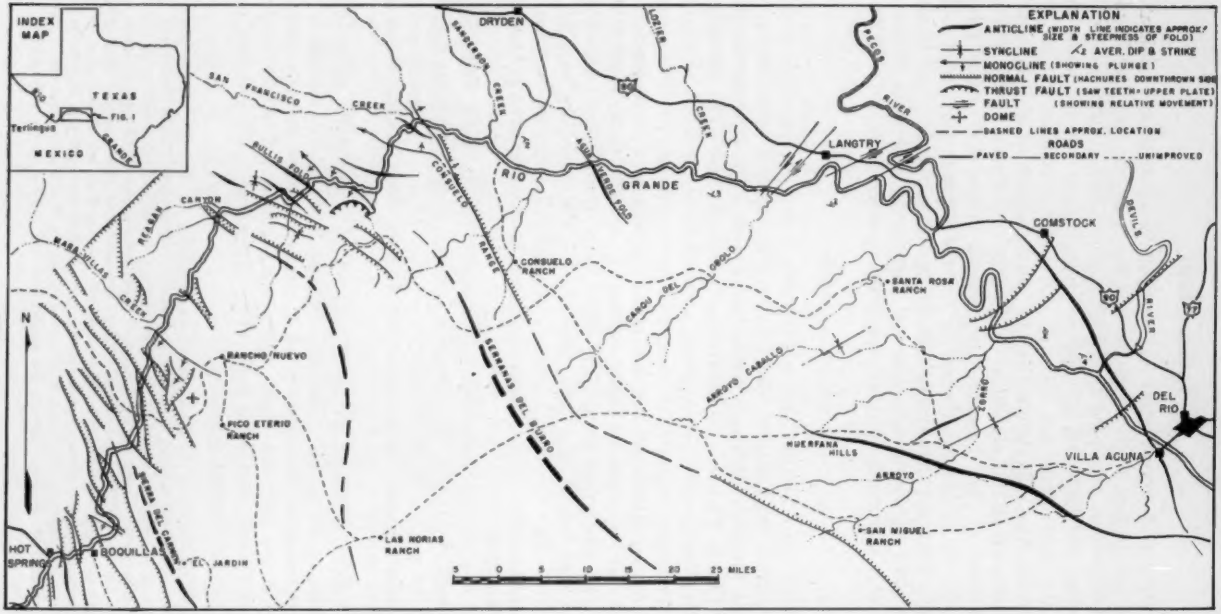

FIG. 1. Structural map, Boquillas to Del Rio-Villa Acuna, Texas-Mexico.

Joints are abundant in all limestone formations, especially where the numerous structural features deformed these brittle beds.

SEDIMENTARY ROCKS.

Rocks of Cretaceous age are the most widespread and consist largely of marine limestone. Their areal distribution is variable, being largely controlled by regional and local structures. However, in general, the older formations are most prevalent upstream, the younger strata downstream (Fig. 1). Thus the Glen Rose formation crops out most extensively near Reagan Canyon while the Georgetown limestone occurs prevailingly in the canyons of the Edwards Plateau with adjacent hills and highlands of the Boquillas formation. A brief description of the lithologic and water-bearing characteristics of the formations cropping out in this section of the "District" are given in Figure 2

Upstream from Boquillas (Fig. 1), a thick series of Upper Cretaceous rocks overlie the Boquillas formation (Fig. 2) and consist of the Terlingua, Aguja, and Tornillo formations with the Tertiary, Chisos beds, composed of volcanics and associated sediments all cropping out in parts of the area. As these Upper Cretaceous and Tertiary rocks are not important in the localization and production of ground water, formations younger than the Boquillas are not included in Figure 2, except for the Quaternary alluviums.

SEQUENCE OF EVENTS.

A brief resumé of the "District's" geologic history will aid in correlating the structural features with development of integrated solutioned openings in the limestones, principal site of ground water localization.[2]

1. A Lower Cretaceous sea inundated the partially beveled Paleozoic rocks with a fairly continuous sequence of marine calcareous and argillaceous deposits laid down up to the close of Georgetown deposition.

2. A slight disturbance at the close of Georgetown deposition apparently upwarped, very gently, a number of northwest-striking flexures; as a result, locally the overlying Del Rio formation was not deposited on the structural and coincident topographic highs (Fig. 2) and the exposed upper Georgetown beds were somewhat altered by solutioning and weathering.

3. Deposition of calcareous and argillaceous material continued during Upper Cretaceous time over the entire area.

4. A regional uplift was initiated by early Tertiary and the stripping of Upper Cretaceous sediments began. Major northwesterly trending structures were initially developed, which included the Del Carmen fold, Terlingua fault, and possibly the Serranias del Burro anticlinorium and some of the gentle flexures of the Edwards Plateau.

5. Tuffaceous sediments and fresh-water limestones with inter-bedded lava flows and tuff were laid down on a dissected surface during early-middle Tertiary time in the upstream sector. Precipitation was considerably greater than today with large bodies of water covering the area intermittently.

[2] Based in part on observations reported by Sellards and Baker (11),[3] King (4), and Goldich and Elms (2).

[3] Numbers in parentheses refer to Bibliography at end of paper.

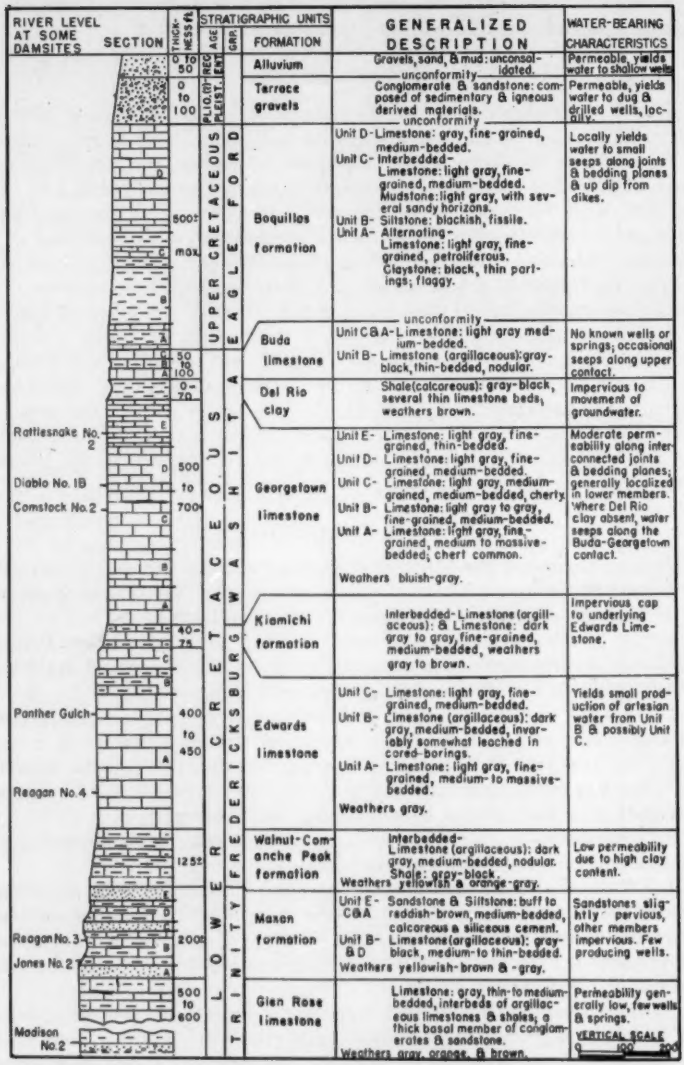
RIVER LEVEL AT SOME DAMSITES
SECTION
THICKNESS ft.
STRATIGRAPHIC UNITS
AGE
FORMATION
GENERALIZED DESCRIPTION
WATER-BEARING CHARACTERISTICS
0 To 50
Alluvium
Gravels, sand, & mud: unconsolidated.
Permeable, yields water to shallow wells
unconformity
0 to 100
Terrace gravels
Conglomerate & sandstone: composed of sedimentary & igneous derived materials.
Permeable, yields water to dug & drilled wells, locally.
unconformity
500± max.
Boquillas formation
Unit D- Limestone: gray, fine-grained, medium-bedded.
Unit C- Interbedded- Limestone: light gray, fine-grained, medium-bedded. Mudstone: light gray, with several sandy horizons.
Unit B- Siltstone: blackish, fissile.
Unit A- Alternating- Limestone: light gray, fine-grained, petroliferous. Claystone: black, thin partings; flaggy.
Locally yields water to small seeps along joints & bedding planes & up dip from dikes.
unconformity
50 to 100
Buda limestone
Unit C & A- Limestone: light gray medium-bedded.
Unit B- Limestone (argillaceous): gray-black, thin-bedded, nodular.
No known wells or springs; occasional seeps along upper contact.
0-70
Del Rio clay
Shale (calcareous): gray-black, several thin limestone beds, weathers brown.
Impervious to movement of groundwater.
Rattlesnake No. 2
Diablo No. 1B
Comstock No. 2
500 to 700
Georgetown limestone
Unit E- Limestone: light gray, fine-grained, thin-bedded.
Unit D- Limestone: light gray, fine-grained, medium-bedded.
Unit C- Limestone: light gray, medium-grained, medium-bedded, cherty.
Unit B- Limestone: light gray to gray, fine-grained, medium-bedded.
Unit A- Limestone: light gray, fine-grained, medium to massive-bedded; chert common.
Weathers bluish-gray.
Moderate permeability along interconnected joints & bedding planes; generally localized in lower members. Where Del Rio clay absent, water seeps along the Buda-Georgetown contact.
40-75
Kiamichi formation
Interbedded- Limestone (argillaceous): & Limestone: dark gray to gray, fine-grained, medium-bedded, weathers gray to brown.
Impervious cap to underlying Edwards Limestone.
Panther Gulch
Reagan No. 4
400 to 450
Edwards limestone
Unit C- Limestone: light gray, fine-grained, medium-bedded.
Unit B- Limestone (argillaceous): dark gray, medium-bedded, invariably somewhat leached in cored borings.
Unit A- Limestone: light gray, fine-grained, medium- to massive-bedded.
Weathers gray.
Yields small production of artesian water from Unit B & possibly Unit C.
125±
Walnut-Comanche Peak formation
Interbedded- Limestone (argillaceous): dark gray, medium-bedded, nodular. Shale: gray-black.
Weathers yellowish & orange-gray.
Low permeability due to high clay content.
Reagan No. 3
Jones No. 2
200±
Maxon formation
Unit E- C & A Sandstone & Siltstone: buff to reddish-brown, medium-bedded, calcareous & siliceous cement.
Unit B- & D Limestone (argillaceous): gray-black, medium- to thin-bedded.
Weathers yellowish-brown & -gray.
Sandstones slightly pervious, other members impervious. Few producing wells.
500 to 600
Glen Rose limestone
Limestone: gray, thin- to medium-bedded, interbeds of argillaceous limestones & shales; a thick basal member of conglomerates & sandstone.
Weathers gray, orange, & brown.
Permeability generally low, few wells & springs.
Madison No. 2
VERTICAL SCALE
0 100 200
LOWER CRETACEOUS
TRINITY
FREDERICKSBURG
WASHITA
UPPER CRETACEOUS
EAGLE FORD
PLIO-PLEIST.
REC.

FIG. 2. Generalized geologic column of outcropping stratigraphic units, Reagan Canyon to Del Rio, Texas, with their water-bearing characteristics.

6. During Miocene (?) —Pliocene (?) time widespread igneous activity was centered to the north and east of the area, and numerous intrusions were emplaced along with some additional outpourings of lava. Contemporaneous with, or closely following this period of intrusion, widespread structural disturbances are believed to have resulted; movement recurred along the early Tertiary northwest structures with additional development of this system. The flexures and northeasterly trending shears and gravity faults of the Edwards Plateau section were developed.

Ore solutions closely followed or accompanied formation of the crustal breaks. Structurally controlled solutioning of the limestone, initiated earlier, facilitated distribution of and deposition from ore solutions; such as the mercury deposits of the Terlingua district and the manganese deposits of the Langtry-Comstock area. Part of the broad upwarping may be due to a doming of the beds by associated igneous intrusives. Crustal adjustments initiated at this time may still be in progress, as a severe earthquake occurred at Valentine, Texas, in 1931 (7, p. 5).

7. Solutioning of the calcareous Cretaceous sediments probably commenced in middle-late Tertiary time along channels offered by various structural breaks. Increased precipitation (as indicated by fresh-water limestones) accelerated stripping and consequently the development of the solutioning.

8. Prolonged erosion since Pliocene-Pleistocene time has filled the intermontane, down-faulted blocks of the Mexican Highlands. Contemporaneously, thick gravels were deposited over parts of the Edwards Plateau.

The ancestral development of the upper Rio Grande is controversial. Some investigators, including P. B. King (4, pp. 256–261), have suggested that as the intermontane basin filling progressed, the individual lake levels were raised until they eventually joined at low mountain passes or by encircling ranges. Consequently, an outlet for the drainage from New Mexico and the "Big Bend" was provided to the headwaters of the ancestral Rio Grande. Maxwell, Lonsdale, and Dickson (5, pp. 51–52), believe the Rio Grande developed its course on top of the volcanics blanketing the area and near their southern edge; as the river was deepened and stabilized, it uncovered and cross-cut buried ridges becoming superimposed upon highlands beneath the volcanic sheet. Others including Udden (13, p. 15), believe the stream is antecedent. Most everyone agrees that the lower consequent course of the Rio Grande existed as early as mid-Tertiary time.

9. Recurring movement, apparently along northwest structures, resulted in downcutting of the Rio Grande with several levels of terracing developed. Consequently, corresponding lower "base-levels of solutioning" were developed in the limestones at elevations above the present stream beds. Some mineralization has been concentrated in sinkholes by meteoric waters; sink structures are undergoing further development.

OCCURRENCE OF GROUND WATER.

General.—Regionally, the direction of underground flow is normal to the Rio Grande; however, flow is parallel and oblique locally. Flowing artesian

wells are known only near Del Rio-Villa Acuna. Many of the wells throughout the area show an artesian effect, particularly those located in the troughs and along the crests of plunging flexures.

The Edwards limestone is the principal aquifer of the region. The upper part of this formation is invariably solutioned, as observed in cored borings throughout the region; it is overlain by the impervious Kiamichi formation and wells producing from the Edwards frequently show an artesian effect.

The younger Georgetown limestone is locally a source of water and the Boquillas and Glen Rose formations have produced relatively small amounts of water under special structural conditions (Fig. 2).

Structural Localization.—Ground water movement is controlled by both structural and stratigraphic conditions. Normally, primary interstitial openings in the limestones are sub-capillary in size and little or no water is transmitted. Consequently, solutioning due primarily to structural control is a major factor in facilitating movement of ground water. Hamilton (3, p. 45–51) discusses and illustrates a pattern that solutional openings develop along joints and bedding planes in a limestone terrain.

Two distinct types of solutioning occur in the "District":

(1) Sinkholes and interconnected tubular openings within the Boquillas, Buda, Del Rio, and Georgetown formations.

(2) Irregular, integrated systems of cavities controlled or associated with faults, joints, and bedding planes, within the Boquillas, Buda, Georgetown, and Edwards formations.

The origin of sink structures in limestone has been widely investigated; Bretz (1) reviews most of the suggested theories of origin. In the "District" the development of sinkholes as recharge "avenues" is believed to be associated with structural features in the following order of importance:

(1) Associated with the crests and troughs of flexures as indicated in the stage diagrams Figure 3. Sinks are 20 to 250 feet in diameter and average 50 feet.

(2) At the intersection of faults and shear zones, in part closely associated with flexures.

(3) At the intersection of joints (Fig. 4) also in part associated with flexures.

In areas of extensive sinkhole development, ground water is produced from the Georgetown limestone in considerable quantities as well as from younger formations locally. Apparently in areas of flexuring, solutioning has developed a system of integrated openings particularly along the strike of the structure. Consequently, wells in these areas of "highs" and "lows" have produced from the shallower Georgetown limestone in addition to the deeper Edwards aquifer. Wells in areas of flatlying, essentially unbroken rocks have produced from the underlying Edwards limestone only.

Cored borings drilled in sink structures demonstrated that solutioning resulted in "slump blocks" of the Del Rio and Buda formations, and in some

places the Boquillas formation subsided considerably below the erosion surface of the Georgetown limestone. Such relations support the belief that solutioning has been active over a long period.

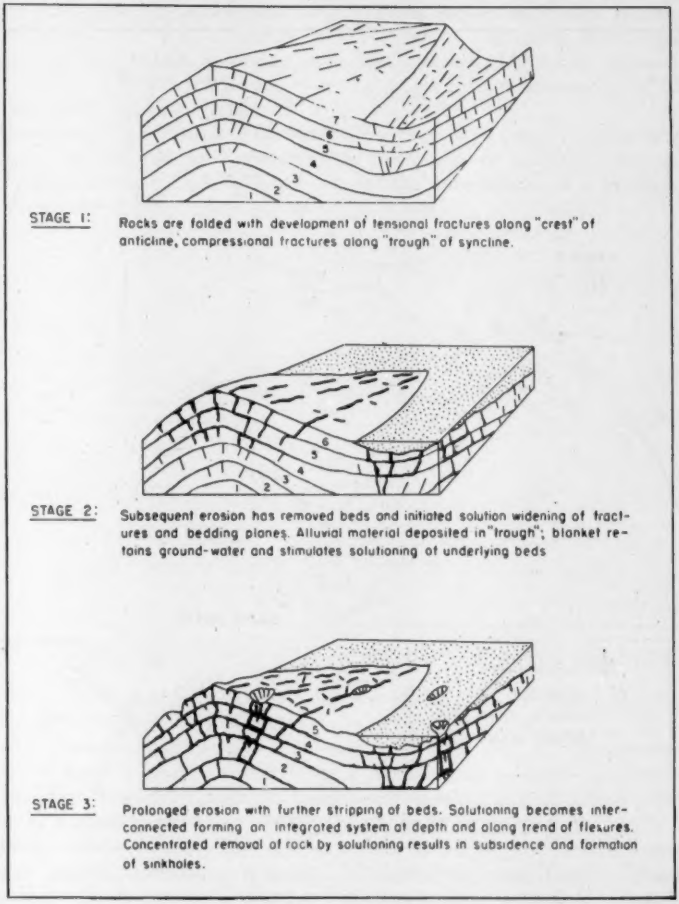
STAGE 1:
Rocks are folded with development of tensional fractures along "crest" of anticline, compressional fractures along "trough" of syncline.
STAGE 2:
Subsequent erosion has removed beds and initiated solution widening of fractures and bedding planes. Alluvial material deposited in "trough"; blanket retains ground-water and stimulates solutioning of underlying beds
STAGE 3:
Prolonged erosion with further stripping of beds. Solutioning becomes interconnected forming an integrated system at depth and along trend of flexures. Concentrated removal of rock by solutioning results in subsidence and formation of sinkholes.

FIG. 3. Schematic stage diagram of sinkhole development associated with flexures.

Solutioned limestone was observed in cored borings drilled hundreds of feet below the static water level and likewise considerably below grade of the Rio Grande. Integrated openings and caves are present above stream grade. Consequently, field observations substantiate the theory of arcuate circulation

(8); an explanation for the development of several "base levels of solution" during entrenchment of the Rio Grande.

In some areas, the ground-water system is a skeletonized pattern confined to the major structural breaks. Borings confirmed this hypothesis in several

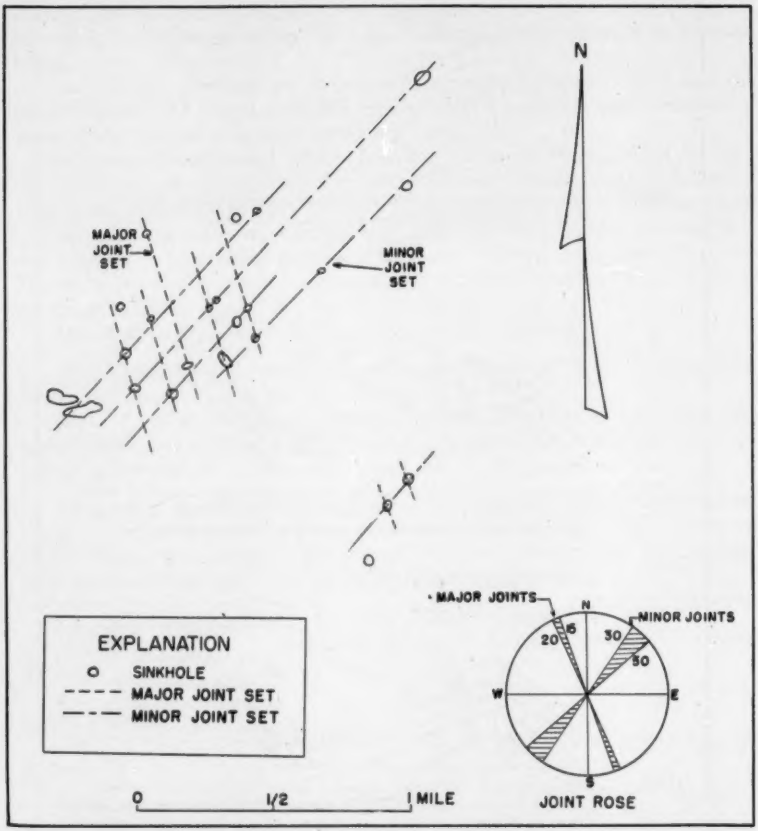

FIG. 4. Typical pattern of sinkhole development associated with joints in the Boquillas formation, near the confluence of Lozier Creek and the Rio Grande.

places; no water could be produced from the Georgetown limestone unless interconnected openings were intersected in the hole. Northeast-trending faults in the Mexican Highlands are tight and did not produce water when drilled (Fig. 1). The measured ground-water level on opposite sides of some major faults proved different.

A deep boring located in the Mexican Highlands and south of the river was "masked" by several northeast faults traversing the intervening area between the hole and the Rio Grande. No water was encountered to a bottom depth of 1,000 feet below the projected level of the nearby river.

An investigation of spring discharge likewise showed a decided structural control (Fig. 5). Major springs in the Mexican Highlands section issue along structural breaks associated with northwestward-trending faults and shears; in the Edwards Plateau section, the major springs are associated with northeastward-trending ruptures.

Economic Significance.—(1) Future selection of water well sites in the "District" should take into consideration the merits of locating wells along the crest and in the troughs of flexures to insure more likelihood of production at a reasonable depth.

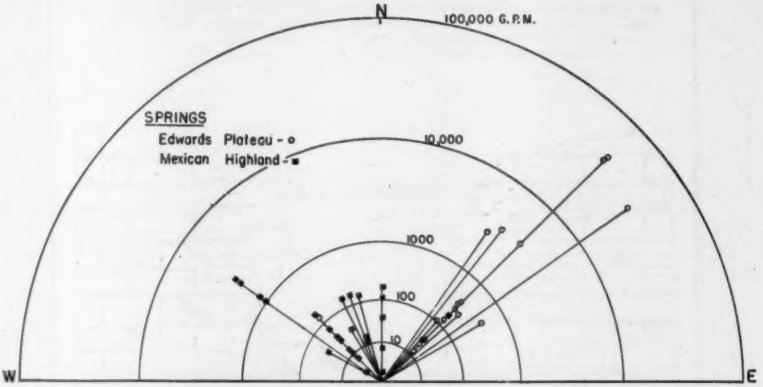

FIG. 5. Diagram of Fault and Shear Zone directions associated with springs.

(2) In areas where the Del Rio clay is absent, the solutioned top of the Georgetown limestone is a potential water producing horizon.

(3) The artesian effect so common in wells associated with flexures must be due, at least in part, to recharge along the plunging structure.

(4) The solutioning with its consequent development of interconnected openings and sink structures apparently began in some areas in middle-late Tertiary. Thus, mineralizing solutions that accompanied the late Tertiary igneous activity found these openings "ideal avenues" and "sites" of deposition. Investigators in the Terlingua district, namely Udden (13), Ross (9), and McAnulty (6), have suggested that solutioning probably pre-dated and guided some ore deposition. A regional study of the structural conditions localizing ground water flow tends to strengthen their hypothesis.

Thompson (12) has suggested a modification in that he believes much of the limestone in the collapsed sink structures was subsequently dissolved at depth by juvenile waters.

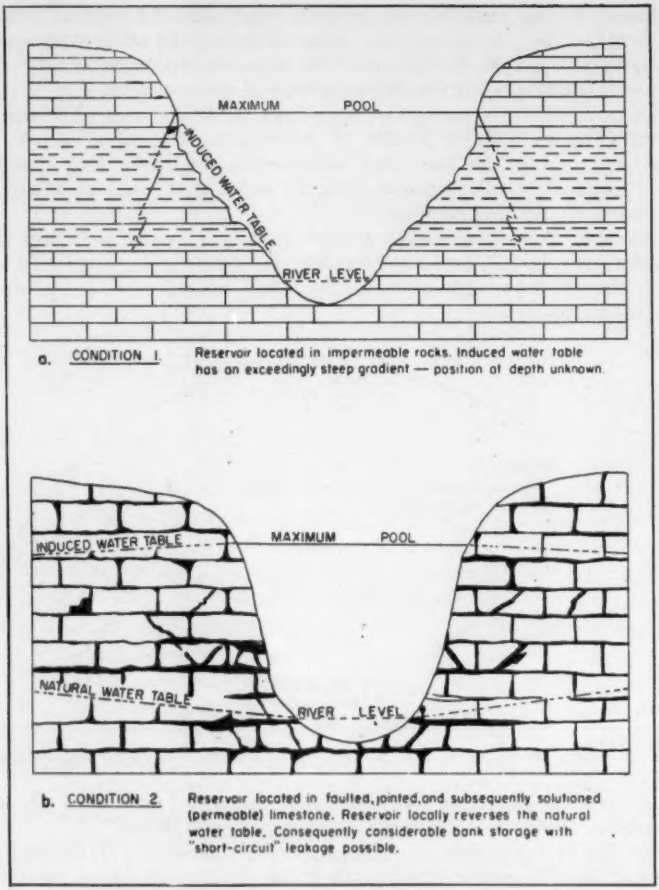
MAXIMUM POOL
INDUCED WATER TABLE
RIVER LEVEL
a. CONDITION 1. Reservoir located in impermeable rocks. Induced water table has an exceedingly steep gradient — position at depth unknown.
INDUCED WATER TABLE
MAXIMUM POOL
NATURAL WATER TABLE
RIVER LEVEL
b. CONDITION 2. Reservoir located in faulted, jointed, and subsequently solutioned (permeable) limestone. Reservoir locally reverses the natural water table. Consequently considerable bank storage with "short-circuit" leakage possible.

FIG. 6. Schematic diagram of some possible reservoir conditions.

(5) Future prospecting in the region may be aided by seeking evidence of solutioning as a guide to ore, particularly as associated with folded areas and the northwestward-trending structures of the Mexican Highlands. Some of the flexures have an igneous "core," and the likelihood of associated mineralization is thereby strengthened.

(6) Synclinal basins with their bedrock masked by a veneer of gravels warrant attention as possible sites of ore deposition (Fig. 3) in sink structures.

Engineering Significance.—Dams and their reservoirs normally create a new natural ground water regimen that is generally attended by a change in

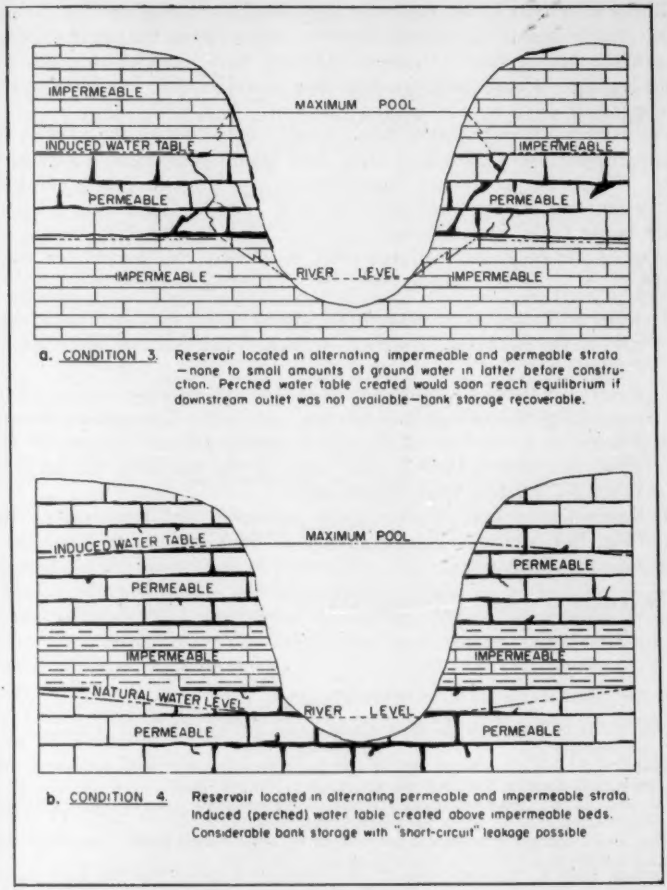
IMPERMEABLE
MAXIMUM POOL
INDUCED WATER TABLE
IMPERMEABLE
PERMEABLE
PERMEABLE
IMPERMEABLE
RIVER LEVEL
IMPERMEABLE
a. CONDITION 3. Reservoir located in alternating impermeable and permeable strata —none to small amounts of ground water in latter before construction. Perched water table created would soon reach equilibrium if downstream outlet was not available—bank storage recoverable.
INDUCED WATER TABLE
MAXIMUM POOL
PERMEABLE
PERMEABLE
IMPERMEABLE
IMPERMEABLE
NATURAL WATER LEVEL
RIVER LEVEL
PERMEABLE
PERMEABLE
b. CONDITION 4. Reservoir located in alternating permeable and impermeable strata. Induced (perched) water table created above impermeable beds. Considerable bank storage with "short-circuit" leakage possible

FIG. 7. Schematic diagram of some possible reservoir conditions.

gradient and hydrostatic head. Most of the dam sites within the "Big Bend District" would be founded on one or more formations consisting primarily of limestone.

Confronted by the conditions of having *first* a limited run-off for conservation and development, and *second* a high rate of evaporation, reservoir sites should then afford a minimum of reservoir loss by leakage to other drainages or "short-circuiting."

Rocks within the lower levels of canyon sections throughout the "District" are invariably weakly solutioned; however, rocks within the upper sections of the canyons are modified by several inherent base levels of solution, which afford leakage. Consequently, a high dam would involve solutioned rocks in the upper part of its foundation and reservoir.

An average transmissibility rate (yearly) for water in the various limestone formations was calculated using data from "pumping-in" tests in drill holes. To simulate conditions representative of a formation, the applied head, and the inherent lithology and structure were varied. Combining the permeability factor for a formation with geological information from borings and outcrops, a set of generalized reservoir conditions was formulated for the "District."

1. Reservoirs located in impermeable rocks (Fig. 6a) that include some sites in the Boquillas, Walnut-Comanche Peak, Maxon, and Glen Rose formations.
2. Reservoirs located in faulted, jointed, and subsequently solutioned limestone (Fig. 6b), which include some sites in the Georgetown limestone.
3. Reservoirs located in alternating impermeable and permeable strata (Fig. 7a), which include some sites in the Kiamichi, Edwards, and Walnut-Comanche Peak formations.
4. Reservoirs located in alternating permeable and impermeable strata (Fig. 7b), which include some sites in the Georgetown, Kiamichi and Edwards formations.

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THE TEXAS COMPANY,
MIDLAND, TEXAS,
June 12, 1952.

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THE APPLICATION OF POLARIZATION FIGURES AND ROTATION PROPERTIES TO THE IDENTIFICATION OF CERTAIN TELLURIDE MINERALS.

DONALD H. HASE.

ABSTRACT.

A study of the polarization figures and rotation properties of certain telluride minerals was undertaken to establish their applicability as a supplementary method of identification of these minerals in polished section. Four properties of the anisotropic tellurides have been investigated: the relative dispersion of the reflection rotation, the apparent angle of rotation, the relative dispersion of the apparent angle of rotation, and the amount of dispersion. The application of these properties to the problem of identification is discussed. The rotation properties, together with physical properties, provide a comparatively rapid and accurate means of identifying most of the anisotropic tellurides. Rotation properties cannot be relied upon, however, for identification of the isotropic members of the group.

INTRODUCTION.

THE study of the application of polarization figures and rotation properties to the identification of certain telluride minerals is part of a larger investigation, now in progress at the University of Wisconsin, designed to ascertain the applicability of polarization figures and rotation properties to the identification of ore minerals in polished section.

The writer was particularly interested in the tellurides because certain members of the group are difficult to identify in polished section and the need for a means of conclusive identification is acute. Physical properties, etch tests, and micro-chemical tests seldom give conclusive results. This is particularly true for gold-silver tellurides and bismuth tellurides. The work of Thompson [1] in applying X-ray techniques to the problem of identification has provided the most positive and reliable method of distinguishing between the minerals of the group, but this requires ready access to X-ray equipment and is a time-consuming procedure.

The purpose of this investigation was to determine the extent to which rotation properties can be used for the identification of the telluride minerals. Identification on the basis of these properties has the advantage that it does not require the use of elaborate or costly equipment beyond that commonly employed in the mineragraphic laboratory. Furthermore, the determinations can be made in conjunction with the routine examination of the ore minerals in polished section, and the time required to identify a mineral in question can therefore be reduced.

[1] Thompson, R. M., The telluride minerals and their occurrence in Canada: Am. Mineralogist, vol. 34, no. 5, pp. 342–382, 1949.

Specimens of all the known tellurides were not available for this study, hence only the more common and available telluride minerals were used.

PROCEDURE.

The following rotation properties were found useful in the identification of the anisotropic telluride minerals.

Relative dispersion of the reflection rotation.

The dispersion of white light that is produced by the reflection of obliquely incident, plane-polarized rays and is due to the difference in the coefficients of refraction and absorption for the various wavelengths of light.

Apparent angle of rotation.

The apparent angle of rotation of the vibration direction of vertically-incident, plane-polarized light produced on reflection from an anisotropic mineral and due to the anisotropy of the mineral.

Relative dispersion of the apparent angle of rotation.

The dispersion of the apparent angle of rotation for various wavelengths of light on reflection from an anisotropic mineral.

Amount of dispersion.

The difference between the apparent angle of rotation for red light and the apparent angle of rotation for blue light.

The reader is referred to the paper by Cameron and Green [2] for a complete explanation of these properties. The remaining properties, the rotation sense and the degree of separation of the isogyres in the field, were not particularly useful in identifying the telluride minerals, and consequently are not included in this study.

The general procedure and apparatus employed in this study have been described by Cameron and Green.[3]

In preparing the polished section for observation, it should be borne in mind that the distinctness of a polarization figure varies to some extent with the degree of the polish of the minerals. Badly scratched surfaces do not give sharp polarization figures. The tellurides are soft and very likely to become scratched during polishing. The problem is not insurmountable, however, if care and patience are exercised. Surfaces used for this study were polished on a Graton-Vanderbilt polishing machine, model G, and were then buffed by hand to remove scratches. Before each examination, the surfaces were buffed and washed to remove any film or tarnish that might affect the figure. Serious errors in the determinations of the rotation properties result if a polished surface that is badly scratched, pitted, or tarnished is used. A perfect polish is not essential but the surface should have small, scratch-free areas if

[2] Cameron, E. N., and Green, L. H., Polarization figures and rotation properties in reflected light and their application to the identification of ore minerals: ECON. GEOL., vol. 45, no. 8, pp. 719–754, 1950.

[3] Op. cit.

figures of maximum distinctness are to be obtained. Hedleyite is a special case. The exsolution texture of the mineral is not apparent until a high degree of polish is obtained.

Formerly, it was thought that precise crossing of the analyzer and polarizer was essential to making accurate determinations of the rotation properties. When the analyzer and polarizer are precisely crossed an undistorted black cross will appear at positions 90 degrees apart on rotation of the stage. Subsequent study has shown that such precise crossing is unnecessary. When the analyzer and polarizer are approximately crossed, the value obtained for the apparent angle of rotation is within the limits of error involved in reading the scale of the analyzer. Considerable time is saved by reducing the number of

TABLE I

ROTATION PROPERTIES OF

ANISOTROPIC TELLURIDES IN AIR

Mineral	Crystal system	Relative dimension of reflection rotation	Apparent angle of rotation	blue	white	red	Relative dispersion of apparent angle of rotation	Amount of dispersion	Figure after rotation of analyser	Figure at 45-degree position. Analyser and polariser crossed.
calaverite	mon	v>r, weak	0	3.5	3.4	3.5	essentially nil	0.0	Gray isogyres. Weak fringes, blue concave, pink convex.	Black isogyres. No color fringes
			C	2.6	2.5	2.6				
krennerite	ort	v>r, weak	0	3.6	4.0	4.6	r>v, moderate	0.7	Black isogyres. Weak fringes blue concave, pink convex.	Gray isogyres. Moderate fringes, blue concave, yellow convex.
			C	2.7	3.0	3.4				
sylvanite	mon	v>r, weak	0	5.3	5.9	6.4	r>v, moderate	0.8	Gray isogyres. Weak fringes, blue concave, red convex.	Black isogyres. Moderate fringes, blue concave, pink convex.
			C	3.9	4.3	4.7				
empressite	?	v>r, moderate	0	2.0	3.3	3.4	r>v, moderate	1.0	Black isogyres. Weak fringes blue concave, yellow convex.	Gray isogyres. Moderate fringes, blue concave, yellow convex.
			C	1.5	2.4	2.5				
hessite	?	v>r, weak	0	0.8	0.6	0.2	v>r, moderate	0.5	Gray isogyres. Weak fringes, blue concave, pink convex.	Black isogyres. Moderate fringes, red concave, blue convex.
			C	0.6	0.4	0.1				
montbrayite	tri	essentially nil	0.	1.7	1.8	2.3	r>v, weak	0.6	Gray isogyres. No color fringes.	Black isogyres. Weak fringes, blue concave, pink convex.
			C	1.3	1.4	1.7				
nagyagite	tet	v>r, moderate	0	0.8	0.7	0.6	v>r, weak	0.2	Black isogyres. Moderate fringes, blue concave, red convex.	Black isogyres. Weak fringes, blue concave, red convex.
			C	0.6	0.2	0.4				
melonite	hex	essentially nil	0	4.6	2.3	2.3	v>r, strong	1.7	Isogyres become diffuse, field becomes bright.	Black isogyres. Strong fringes, yellow concave, blue convex.
			C	3.4	1.7	1.7				
tetradymite	hex	v>r, weak	0	1.1	0.6	0.6	essentially nil	0.4	Gray isogyres. Weak fringes, blue concave, pink convex.	Gray isogyres. No color fringes.
			C	0.8	0.4	0.4				
tellurbismuth	hex	essentially nil	0	2.0	1.2	1.0	v>r, moderate	0.8	Gray isogyres. No color fringes.	Black isogyres. Moderate fringes, pink concave, blue convex.
			C	1.5	0.9	0.7				
rickardite	tet	r>v, moderate	high				strong	?	Grey isogyres. Strong fringes, fiery-orange concave, blue convex.	Red isogyres. No color fringes.

* not diagnostic

manipulations necessary to effect a precise crossing of the analyzer and polarizer.

The surfaces studied contained randomly-oriented grains of the minerals. Those grains showing high anisotropism were selected for study on the assumption that only those grains that show high anisotropism will give values approaching the characteristic value of the apparent angle of rotation at the 45-degree position. If the angles are measured for a series of such grains, the maximum value obtained should be close to the characteristic value. In Table I and Table II, the observed maximum angles of rotation at the 45-degree position are tabulated. It should be noted, however, that the value given in the tables for a mineral cannot be proved to be the true maximum value

of the apparent angle of rotation, because oriented sections could not be prepared from the material available. It is possible that none of the grains in the surface was so oriented as to show maximum anisotropism. The writer believes, however, that the tabulated values approximate the characteristic values within the limits of error of measurement.

The reader will note that two values, an observed value and a corrected value, are given for the apparent angle of rotation of each mineral in Table I. Recent investigation at this university has shown that the observed value of the apparent angle of rotation is partly due to the glass plate in the reflecting unit of the microscope system. The rotation produced by the glass plate varies with the individual microscope. For the microscope used in this investigation

TABLE II

ROTATION PROPERTIES OF

ANISOTROPIC TELLURIDES IN OIL, n=1.515

Mineral	Crystal system	Relative Dispersion of Reflection Rotation	Apparent angle of rotation			Relative dispersion of apparent angle of rotation	Amount of dispersion	Figure after rotation of analyser	Figure at 45-degree position. Analyser and polarizer crossed.
			blue	white	red				
calaverite	mon	essentially nil	5.2	5.2	5.8	essentially nil	0.6	Black isogyres. No color fringes.	Black isogyres. No color fringes.
krennerite	ort	r>v, weak	1.2	1.6	0.9	essentially nil	0.3	Gray isogyres. Weak fringes, blue concave, pink convex.	Gray isogyres. No color fringes.
sylvanite	mon	r>v, moderate	10.0	11.5	11.0	r>v, moderate	1.0	Gray isogyres. Moderate fringes, blue concave, red convex.	Gray isogyres. Moderate fringes, blue concave, red convex.
empressite	?	r>v, moderate	?	4.1	5.2	r>v, strong	?	Gray isogyres. Strong fringes, blue concave, yellow convex.	Gray isogyres. Strong fringes, blue concave, yellow convex.
hessite	?	r>v, weak	2.3	1.4	0.6	r>v, weak	0.9	Gray isogyres. Weak fringes, blue concave, pink convex.	Gray isogyres. Weak fringes, pink concave, blue convex.
montbrayite	tri	r>v, weak	2.3	3.4	2.9	r>v, weak	0.6	Gray isogyres. Weak fringes, blue concave, pink convex.	Gray isogyres. Weak fringes, blue concave, pink convex.
nagyagite	tet	r>v, weak	1.1	1.4	1.4	essentially nil	0.3	Black isogyres. Weak fringes, blue concave.	Black isogyres. No color fringes.
melonite	hex	essentially nil	9.3	4.0	3.2	r>v, strong	5.5	Black isogyres. Indistinct fringe, blue concave.	Gray isogyres. Strong strong fringes, yellow concave, blue convex.
tetradymite	hex	essentially nil	1.2	1.4	1.4	essentially nil	0.2	Black isogyres. No color fringes.	Black isogyres. No color fringes.
tellurbismuth	hex	r>v, weak	2.8	2.9	2.9	essentially nil	0.1	Black isogyres. Weak fringe, blue concave.	Black isogyres. No color fringes.
rickardite	hex	r>v, moderate	high			strong	?	Gray isogyres. Strong fringes, fiery-orange concave, blue convex.	Red isogyres. No color fringes.

the rotation produced by the glass plate is approximately one degree for each five degrees of observed rotation, and is in a positive sense. Hence, the applied correction was subtracted from the observed value of the apparent angle of rotation to give the corrected value.

RESULTS.

The tellurides fall into two groups, the isotropic and the anisotropic members.

Anisotropic Tellurides.—The rotation properties of the anisotropic tellurides studied are given in Tables I and II. As indicated by the data, calaverite, krennerite, and sylvanite can be distinguished in polished section on the bases of their relative dispersions of the apparent angle of rotation, relative

dispersions of the reflection rotation, and their apparent angles of rotation when the immersion medium is air. At the 45-degree position, the figure produced by calaverite has no color fringes, that produced by krennerite has a blue fringe on the concave side of the isogyres and a yellow fringe on the convex side, and that produced by sylvanite has a blue fringe on the concave side of the isogyres and a pink fringe on the convex side. Also, reference to Table I will point out the diagnostic differences in the values of the apparent angles of rotation. In oil immersion, the differences among the apparent angle of rotation (Table II) are so great that rough measurements are adequate to distinguish the minerals. The results of the investigation suggest that herein lies the answer to the long-standing problem of distinguishing between these minerals in polished section. Etch tests have not proved of great value in identifying these tellurides. Short [4] concludes, "The results of etching the three tellurides are not as simple and conclusive as had been hoped for."

The mineral empressite exhibits a slight tendency toward elliptical polarization. Owing to this phenomenon, it is difficult, sometimes impossible, to restore the black cross by rotating the analyzer when the mineral is in the 45-degree position. In oil immersion, the isogyres in blue light are so indistinct that no determination of the apparent angle of rotation is possible. The appearance of the polarization figure upon rotation of the analyzer, and the appearance of the figure at the 45-degree position help to identify empressite. The figures have blue fringes on the concave side of the isogyres and yellow fringes on the convex side.

The investigation of hessite shows that some grains of the mineral are isotropic, whereas other grains are moderately anisotropic. Thompson,[5] on the basis of X-ray studies, concludes that the crystal system of hessite is unknown. Short [6] classes the mineral as isotropic, but states that most of the grains show anomalous anisotropism. The polarization figure of hessite in the 45-degree position shows red fringes on the concave sides of the isogyres and blue fringes on the convex sides. The values of the apparent angles of rotation in white and monochromatic light are sufficiently different from those of any of the other tellurides to permit distinction of hessite on this basis.

The figure produced by montbrayite upon rotation of the analyzer has no color fringes. The figure in the 45-degree position shows only weak fringes with a pale blue fringe on the concave side of the isogyres and a pink fringe on the convex side. Montbrayite can be identified, however, on the basis of its apparent angles of rotation in white and monochromatic light.

The peculiar behavior of the polarization figures and rotation properties of nagyagite warrants a detailed discussion. The following explanation of the behavior is based on the theory of polarization figures as proposed by Cameron and Green.[7]

[4] Short, M. N., Etch tests on calaverite, krennerite, and sylvanite: Am. Mineralogist, vol. 22, no. 5, pp. 667–674, 1937.

[5] Op. cit.

[6] Short, M. N., Microscopic determinations of the ore minerals: U. S. Geol. Survey Bull. 914, 2nd ed., p. 126a, 1948.

[7] Cameron, E. N., and Green, L. H., Polarization figures and rotation properties in reflected light and their application to the identification of ore minerals: Econ. Geol., vol. 45, no. 8, pp. 720–740, 1950.

In white light, the figure produced by rotation of the analyzer has black isogyres with moderate color fringes, blue on the concave sides of the isogyres, and red on the convex sides. Therefore, the reflection rotation is greater for blue light than for red. In the 45-degree position with crossed nicols, the figure has gray isogyres with weak to moderate color fringes, blue on the concave sides of the isogyres, and pink on the convex sides. The disposition of the color fringes suggests that the rotation angle is greater for red light than for blue. Although the disposition is the same, the intensity of the color fringes differs on the two figures. The fringes on the figure produced by the mineral in the 45-degree position are weaker. When the mineral is in the 45-degree position, the intensity of the color fringes is reduced if the dispersion of the reflection rotation and the dispersion of the apparent angle of rotation offset each other.[8] Hence, the difference of intensity suggests that the dispersion of the apparent angle of rotation is greater for blue light than for red light. Measurements of the apparent angles of rotation in monochromatic light indicate that the rotation is greater for blue light than for red light.

The apparent angle of rotation for nagyagite in white light is considerably less than for either red or blue light. The writer is unable tc explain this phenomenon. It should be noted that rotation of the analyzer does not produce a distinct black cross. This might possibly be explained on the assumption that owing to elliptical polarization no true extinction position can be reached, even if the analyzer is rotated 360 degrees. An attempt was made to approximate the crossed position, but a low anomalous value resulted for white light. The value is entered in Table I for completeness sake, but should in no way be considered diagnostic for the mineral. The effect of elliptical polarization was noted also for the wavelengths of red and blue light in that the cross was weak and gray and not distinct and black.

The figure observed for melonite at the 45-degree position in white light has a distinct disposition of color fringes that is not duplicated by any other telluride that was studied. The figure has an intense yellow fringe on the concave sides of the isogyres and an intense blue fringe on the convex sides. The amount of dispersion is the greatest of any of the minerals studied and is considerably greater than any of them.

The polarization figures produced by tetradymite are similar to those produced by calaverite. When the mineral is in a position of extinction, rotation of the analyzer causes the cross to separate into gray isogyres with weak fringes, blue on the concave sides, and pink on the convex sides. In the 45-degree position, the figure has no color fringes. The apparent angles of rotation in white and monochromatic light, however, are sufficiently different from the rotation angles of other telluride minerals observed to allow identification.

On rotation of the analyzer from an extinction position tellurbismuth produces a figure that has no color fringes. In the 45-degree position, the figure for tellurbismuth has moderate color fringes; pink on the concave sides of the isogyres, blue on the convex sides. The apparent angles of rotation of the mineral can be used to differentiate tellurbismuth from the other telluride minerals.

[8] Cameron, E. N., and Green, L. H., op. cit., pp. 738–741.

Rickardite can be identified readily by its color, pleochroism, and vivid polarization colors. No other telluride mineral resembles rickardite in these properties. Upon rotation of the analyzer from an extinction position, the cross separates into gray isogyres with a distinct, fiery-orange fringe on the concave sides of the isogyres and a blue fringe on the convex sides. The apparent angles of rotation of rickardite are believed to be high, but no values could be obtained because the mineral apparently exhibits a high degree of ellipticity. In the 45-degree position, the isogyres are red and distinct. Rotation of the analyzer, however, does not produce a cross. Rather, the entire field is fiery-orange, and no isogyres are visible.

The available section of hedleyite could not be used in this study. When the surface was highly polished, many tiny, included, yellowish blebs became visible. Consistent determinations of polarization figures and rotation properties were impossible because of this exsolution texture.

It was likewise impossible to make determinations of the rotation properties of weissite and frohbergite. Weissite occurs in sponge-like masses with gangue filling the cavities and has a fine-grained, mosaic texture. Frohbergite is also fine-grained and commonly occurs in narrow zones around larger grains of other minerals with which it is associated. A mechanical difficulty in maintaining the centering of the objective was encountered when dealing with excessively fine-grained minerals.

Samples of csiklovaite, gruenlingite, joseite, and wehrlite were not available for study and consequently are not included in the determinative tables.

The reader has probably noted in the foregoing discussion that the apparent angles of rotation, in white and monochromatic light, are far more useful for purposes of identification than are the relative dispersion of the reflection rotation and the relative dispersion of the apparent angle of rotation. This is also true when the properties are studied using oil as the immersion medium.

The apparent angle of rotation changes as the immersion medium is changed from air to oil. The changes vary with each mineral and are functions of the optical constants of the mineral.[9] In most cases, the use of oil as an immersion medium increases the apparent angles of rotation. Oil immersion produces a much darker and more distinct figure, but the angles of rotation cannot be determined as accurately. A degree of rotation of the analyzer will cause the isogyres to move a greater distance in the field when the immersion medium is air than it will when the immersion medium is oil. Hence, the point at which the black cross is restored on rotation of the analyzer can be determined more accurately in air.

Isotropic Tellurides.—The isotropic tellurides, petzite, altaite, coloradoite, and collusite, cannot be distinguished from each other on the basis of their polarization figures. In every case, the dispersion due to the reflection rotation is greater for blue light than for red light. The minerals differ slightly in the intensity of the color fringes shown by their figures when the analyzer is rotated, but the differences are not sufficient for identification.

[9] Cameron, E. N., The influence of the immersion medium on the rotation properties of anisotropic minerals in reflected light: Econ. Geol., vol. 46, no. 1, pp. 68–75, 1951.

CONCLUSIONS.

Polarization figures and rotation properties can be used to help identify most of the anisotropic telluride minerals. The method should be particularly successful for calaverite, krennerite, and sylvanite. The rotation properties of the other anisotropic tellurides are sufficiently different to distinguish between them.

The method, however, is not the final answer to the problem of identifying all the telluride minerals in polished section. When dealing with the extremely fine-grained minerals the objective must be precisely centered on an individual grain during observation. With the microscope set-up that was used in this study, it was extremely difficult to maintain perfect centering of the objective. Consequently, determinations of the rotation properties could not be made because the objective could not be kept centered on a single grain. The writer believes that the loose threads in the mechanical stage used was one of the contributing factors to this difficulty. Also, a Bausch and Lomb objective was employed for part of the investigation and in order to center this objective on the Spencer microscope, the adjusting screws had to be set near the ends of the threads and did not hold the collar as securely as could be hoped. The slightest jar of the set-up caused the objective to move off center. This difficulty was not quite as apparent when using the Spencer objective. This is meant to be a statement of some of the difficulties encountered and not a criticism of the Spencer microscope.

The method contributes nothing to the problem of identifying the isotropic tellurides beyond dividing the isotropic members from the anisotropic members of the group.

Polarization figures and rotation properties in themselves, therefore, do not permit positive identification of all the tellurides. When the method is used as a supplement to the physical properties of the minerals in polished section, however, a rapid and accurate identification of the majority of the telluride minerals can be made.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge the helpful criticism of Professor E. N. Cameron, Department of Geology, University of Wisconsin, during the preparation of this paper. He also wishes to thank Professor R. M. Thompson, Department of Geology, University of British Columbia, and Dr. E. P. Henderson of the United States National Museum, for providing identified specimens of the tellurides used in this study.

UNIVERSITY OF WISCONSIN,
MADISON 6, WIS.,
June 23, 1952.

GEOLOGY AND MINERALIZATION OF THE VOLCANO DISTRICT, ELMORE COUNTY, IDAHO.*

RHESA M. ALLEN, JR.

ABSTRACT.

The gold-silver base metal-quartz veins and lodes of the Volcano district are located along the south margin of Camas Prairie in Elmore County, Idaho. The veins and lodes are fissure fillings with minor replacements intimately associated with granophyric dikes, both of an early Tertiary age, and are localized by an east-northeast shear zone in a quartz monzonite facies of the Idaho batholith. The emplacement of the dikes and mineralized veins was controlled by fractures resulting from the Laramide disturbance. The deposits have been exhumed from beneath a cover of Pliocene rhyolite and Pleistocene basalt.

The vein and lode deposits consist of networks of small quartz seams and stringers with a N 60–70° E trend and steep northwest dips along complex fracture zones. The lodes have been worked for gold, although all contain minor amounts of silver, copper, lead, and zinc.

Wall rock alteration appears excessive for the small degree of metallic mineralization. Sericitization, silicification, albitization, and epidotization, in that order, have highly altered the monzonitic rock for distances up to 25 feet adjacent to the veins and lodes.

INTRODUCTION.

THE Volcano mining district, which lies astride the boundary between Elmore and Camas Counties, Idaho, about 25 miles by road west-southwest of Fairfield (Fig. 1), embraces an area of more than usual geologic interest, principally because of certain features of its mineralization and attendant wall rock alteration.

The district contains a number of gold-silver base metal veins and lodes that are grouped along a zone of structural weakness that extends in an east-northeast direction close within the southern boundary of the Idaho batholith. The veins and lodes constitute fissure fillings and replacements with some of the textural and mineralogical characteristics of the gold-bearing lodes of the Rocky Bar district,[1] the silver-gold lodes of the Atlanta district,[2] both of which are some 35 to 40 miles north of the Volcano district, and of the gold-bearing lodes along the Hailey gold belt,[3] which lies some 45 miles to the northeast. Although possessing some of the textural, structural, and min-

* Presented at the November 16–18, 1950, meeting of the Geological Society of America, and the Society of Economic Geologists, Washington, D. C.

[1] Anderson, A. L., Geology of the gold-bearing lodes of the Rocky Bar district, Elmore Co., Idaho: Idaho Bur. Mines and Geology Pamph. 65, 1943.

[2] Anderson, A. L., Geology and ore deposits of the Atlanta District, Elmore Co., Idaho: Idaho Bur. Mines and Geology Pamph. 49, 1939.

[3] Anderson, A. L., and Wagner, W. R., A geologic reconnaissance of the Hailey Gold Belt (Camas District), Blaine Co., Idaho: Idaho Bur. Mines and Geology, Pamph. 76, 1946.

eralogic features of these other districts, the Volcano district nevertheless has some features particular to itself and thus merits description. These deposits have received brief mention by Bell,[4] and Piper [5] has summarized the general geology and ground water resources of the region immediately east of the district.

FIG. 1.

GEOLOGIC SETTING.

The deposits are exposed along the frontal scrap of a low tilted mountain block that forms the south boundary of a broad, east-west intermontain basin known as Camas Prairie, a product of faulting and downwarping of late Tertiary and probably Quaternary time. They are contained wholly within the rock of the Idaho batholith, in part across related aplite dikes and in part across

[4] Bell, R. N., Another Butte in southern Idaho: Mining Truth, 15th year, no. 19, November, 1930.

[5] Piper, A. M., Ground water for irrigation on Camas Prairie, Camas and Elmore Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 15, 1926.

granophyric dikes of probable early Tertiary age. The deposits are much older than flows of rhyolite of Pliocene age which cap an erosion surface of the batholithic rock a short distance to the south, and the still younger flows of basalt of Pleistocene age that have spread over the rhyolite and lie beneath the alluvial fill of Camas Prairie (Fig. 2).

Structurally, the deposits appear to be grouped along one of the zones of structural weakness that developed in the Idaho batholith during the Laramide

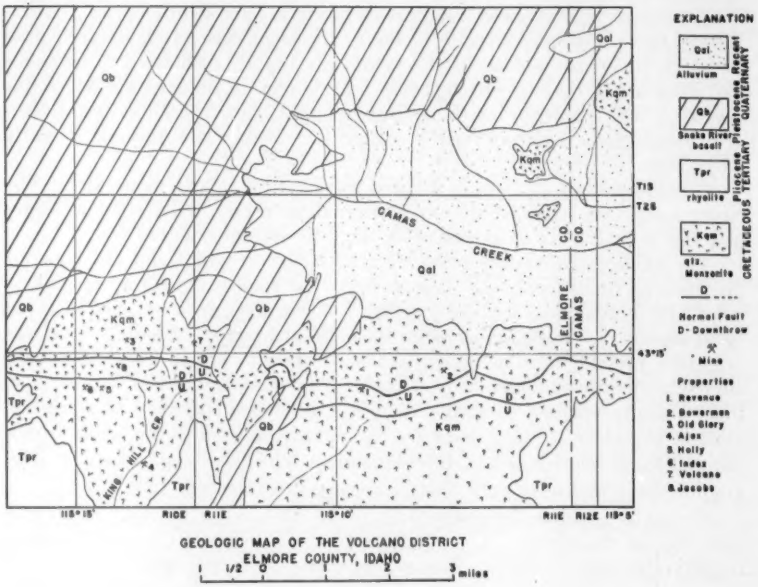

FIG. 2.

orogeny, when forces were transmitted unequally against the Laramide trough then undergoing deformation.[6]

DESCRIPTION OF HOST ROCKS.

The grantitoid rock that underlies the district is similar to the rock that makes up the main mass of the Idaho batholith throughout the central part of Idaho and is almost wholly quartz monzonite. As shown on Figure 2, the quartz monzonite exposure is confined to the region southwest of Camas Prairie, although small masses protrude through basalt and alluvium. The rock, as a whole, is coarse-grained, and is gray to white in color. In places

[6] Anderson, A. L., Role of Idaho batholith during the Laramide orogeny: ECON. GEOL., vol. 43, no. 2, pp. 84–99, 1945.

it is somewhat porphyritic and contains microcline phenocrysts which are as much as twenty millimeters in length. These phenocrysts are flesh-colored and give the rock a pinkish, mottled appearance. Generally the rock contains 8 percent or less of biotite and 2 percent or less of hornblende. The principal minerals of the quartz monzonite are: quartz, about 35 percent; microcline-orthoclase, 30–25 percent; oligoclase-andesine (An_{35} to An_{25}), 30 percent or less. The balance of the rock is biotite, hornblende, and the accessory minerals sphene and magnetite with a slight amount of epidote and allanite. Biotite is always partly, and in some instances completely, altered to chlorite. Hornblende shows some alteration to biotite. The plagioclase is highly sericitized and with the potash feldspar is also commonly slightly epidotized. Remnants and shadow-like outlines of plagioclase can be seen in some of the microcline crystals. The age of the quartz monzonite of the Idaho batholith, on the basis of evidence gathered from nearby areas,[7] is probably late Jurassic or early Cretaceous.

Numerous dikes of aplite and granophyre cut the quartz monzonite. The larger bodies are prominently exposed on ridge crests and form low ledges that can be traced for distances of as much as several hundred feet.

The aplite dikes are not more than 12 inches in width and crop out for distances up to 50 feet along their strike. The rock is light gray to pink in color, and its texture is decidedly aplitic. These dikes are composed of about equal amounts of quartz, calcic oligoclase, and orthoclase. Biotite, which was originally present in an amount less than 5 percent, has in most cases been altered to chlorite or muscovite. Titanite, magnetite, and zircon also occur in small quantity. Finely divided sericite has developed sparingly as a replacement of oligoclase. These dikes are undoubtedly related to the Idaho batholith and have been formed as differentiates of the underlying, slowly cooling, granitic mass, and were very likely emplaced in Cretaceous time.

Granophyric dikes are common in the district, although they are not as numerous as the aplites. They vary in width from 2 to 10 feet and average roughly 100 feet in length. The granophyres are mostly pink in color and have textures that range from granophyric to hypidiomorphic-granular. Many closely approach a porphyritic habit, with quartz phenocrysts from one to five millimeters in diameter set in a micropegmatitic groundmass. These special porphyritic phases that could perhaps rightly be called quartz porphyries, contain rounded quartz crystals that are commonly embayed by micropegmatitic intergrowths. Mineralogically, the granophyres are similar to the aplites. Quartz and potash feldspar comprise about 90 percent of the rock. Calcic oligoclase and small fragments of biotite make up the remainder. The potash feldspar (mainly orthoclase) occurs wholly as a micropegmatitic intergrowth with quartz. Calcic oligoclase crystals are moderately common, although all are highly sericitized. The age of these dikes is difficult to determine. Their silicic and alkalic compositions and fine texture suggests an end-

[7] Ross, C. P., Mesozoic and Tertiary granitic rocks in Idaho: Jour. Geology, vol. 36, no. 8, p. 692, 1928. Some features of the Idaho batholith: 16th Internat. Geol. Cong. Rept., pp. 382–383, 1936.

stage fluid emplaced in relatively cold host rock. Anderson[8] suggests an early Tertiary age for them and would not consider them to be genetically related to the Idaho batholith.

MINERALIZATION.

General Character of the Deposits.—Practically all of the lode deposits consist of networks of small quartz seams and stringers along complex fracture zones, cutting quartz monzonite, aplite, and granophyre. Individually, the mineralized veins vary greatly in width and length. The average width of the veins that have been mined ranges from 3 to 6 inches, and as it is usual to find several of these veins or veinlets paralleling each other and enclosing a few feet of highly altered wall rock, the entire lode was mined as a unit. It is rare that the average lode extends for more than 100 feet along the strike, but it pinches out, and farther along the strike swells again. The largest vein noted (Revenue Claim—Fig. 2) varies from 8 to 15 feet wide and can be traced for approximately 1,000 feet along the strike.

The general trend of the lodes is about N 70° E and the dips vary from 55° NW to vertical. A few veinlets follow joint openings with a N 10–15° W trend, but generally the individual vein networks are parallel and have an easterly trend. In addition, the deposits as a whole are grouped in an east-west shear zone roughly 10 miles in length, which served as the structural framework for the intrusion of granophyric dikes and mineralizing fluids.

The zones of fracture occupied by the lodes are from 5 to 25 feet wide with an average width of approximately 10 feet. The larger concentrations of metallic minerals mostly occur at the locus of intersecting fractures within a major shear or fracture zone. There has also been minor post-mineral faulting and shearing along the veins.

The lodes have been worked primarily for their gold content, although all contain minor amounts of galena, spalerite, chalcopyrite, and pyrite. Much of the gangue is quartz with subordinate amounts of calcite. Both fracture filling and replacement processes have been operative, with vein filling of quartz and metallic minerals the more common for the productive deposits and with extensive wall rock alteration adjacent to the veins. The veins and lodes occupy quartz monzonite and granophyre alike, with the smaller veinlets occupying fractures in the granophyre. Commonly, numerous angular inclusions of silicified dike rock are present in the vein material, resulting in breccia lodes.

Mineralogy of the Lodes.—The veins and lodes of the district are composed of quartz containing varying amounts of pyrite, chalcopyrite, argentiferous galena, sphalerite, magnetite, specular hematite, and gold. Calcite is also present in the veins in small quantities. In the zone of oxidation and associated with the outcrop are several secondary minerals of iron, copper, and lead.

Quartz is by far the most abundant mineral of the lodes and three varieties of quartz appear to be present. A massive, medium-grained, milky quartz is present as a fissure filling and as a cement for the finely brecciated country

[8] Anderson, A. L., Personal Communication.

rock in shear zones. This quartz has the appearance of having been in turn brecciated and then cemented with a dark, fine-grained quartz. A third variety of quartz, clear and coarse-grained, occurs as comb quartz in open fractures. The manner of occurrence of these three varieties suggests three stages of deposition.

The metallic sulfides are minor in quantity insofar as present developments would indicate, with galena and chalcopyrite leading in abundance in that order. Gold is the most important mineral, economically, of the deposits. Practically all of the gold is microscopic in size and is present in the combs and druses of the third stage quartz as minute granules and as minute veinlets penetrating fractures in earlier minerals.

Studies of hand specimens and polished sections indicate that the minerals of the lode deposits have not resulted from simultaneous and strictly contemporaneous deposition. All available evidence points towards three stages of mineralization. Each stage was preceded by fracturing and reopening along the zones of weakness that permitted the ascension of the ore-bearing fluids. Slight brecciation accompanied the fracturing and reopening of the fissures, and breccia fragments can be observed in the later quartz fillings. The structural adjustments and recurrent surges of mineralizing fluids occupied a very brief space of time geologically.

The paragenetic order of the minerals appears to be as follows: The first invasion of mineralizing fluids into the zones of fractured monzonite and granophyre introduced large amounts of quartz and a very small amount of pyrite. Wide scale fracturing and reopening with some minor brecciation of the early quartz filling preceded the introduction of a second generation of a finer-grained quartz. With this fine-grained quartz; pyrite, chalcopyrite, sphalerite, and galena were deposited in the order given, the quartz preceding and in part accompanying the deposition of the metallic compounds. Structural adjustments were again active following the deposition of the metallic sulphides. In the openings that resulted from this fracturing a third generation of coarse-grained quartz, which was accompanied by gold and a very small amount of pyrite, was deposited as drusy and comb structures in open fractures. The mineralizing epoch was closed by the deposition of calcite in thin veinlets.

WALL ROCK ALTERATION.

Alteration of the country rock is prevalent within the vein zones and extends outward for several feet on either side of any particular zone of mineralization. The degree of alteration is irregular and the type of alteration varies with each individual lode. The introduction of sericite, quartz, and epidote into the wall rock is the most conspicuous alteration feature of the east trending lodes. Some slight amounts of sericite and silica have replaced, for a few inches, the wall rock of the north-northwest trending veinlets.

The plagioclase feldspars suffered the most during replacement processes, because closely adjacent to the lodes they are wholly replaced by sericite. Hornblende exhibits biotite replacement rims, and primary biotite has been altered to muscovite and subordinate chlorite. In addition, silica has permeated

much of the rock adjacent to the lodes, and has replaced much of the feldspar and micas. Minute stringers of quartz permeate much of the rock, forming a network throughout the entire bordering zone and locally has given the rock a quartzitic appearance. Epidote in fine-grained masses permeates much of the wall rock immediately adjacent to the larger lodes. With the epidote are quantities of disseminated pyrite, magnetite, and specular hematite. Fresh albite is evident in association with epidote. The albite rims sericitized plagioclase feldspars and also occurs as minute veinlets scattered throughout the rock mass. Late chlorite is present as a replacement of biotite and hornblende and as small veinlets that cut through epidotized rock. The effects of the altering fluids are evident in thin sections made from samples taken as far as 25 feet outward from the mineralized veins of easterly trend. Close to the veins the rock has taken on a bleached appearance and has a soft talc-like feel.

The change in the mineralogy of the country rock as outlined above affected the quartz monzonite to a much greater degree than the granophyric dikes and these changes occurred in a well defined sequence of alteration. Sericitization of the monzonitic rock was the first alteration process. Silification followed, and whereas in some areas the introduction of silica only partially replaced sericitized rock, in other areas it has completely engulfed the previously altered rock.

The addition of albite, followed by epidote, is superposed on fractured zones of silicified and sericitized rock. Thin section studies indicate the albite predates epidote. Chlorite, as veinlets in epidotized rock, indicates a late age for its entry.

CONCLUSIONS.

The gold-base metals veins and lodes of the Volcano district are localized along an east trending shear zone in quartz monzonite of the Idaho batholith. Associations between the ore-bearing lodes and granophyric dikes in this area, as well as similar relations elsewhere in the central Idaho region, indicate some genetic connection between the lodes and dikes. The granophyric dikes are younger than, and are not likely associated genetically with the batholith, but represent differentiates of a deep-seated early Tertiary magma with a later phase of this differentiation expressed in the veins and lodes. Repeated fracturing characterized the period of granophyre-vein introduction. The intense and widespread nature of the wall rock alteration, with indications of a rise in temperatures late in the depositional sequence as evidenced by late additions of albite and epidote, gives this deposit a somewhat different mineralogic history as compared with the deposits of contiguous districts.

ACKNOWLEDGMENTS.

The writer is greatly indebted to Dr. A. L. Anderson of Cornell University for guidance while in the field and for critical reading of the manuscript.

FRENCH COAL COMPANY,
BLUEFIELD, W. VA.,
July 29, 1952.

DISCUSSION

SOME PIPE DEPOSITS OF EASTERN AUSTRALIA.

Sir: The writer published in ECONOMIC GEOLOGY some observations about tin deposits in Australia.[1] For four and a half years the writer has not seen any of the technical magazines from Australia. Therefore, until recently, the papers of Stillwell [2] and Edwards [3] did not come to the attention of the writer.

The writer in his tin deposits in Australia divided the subject in two forms. 1. "Pipe Deposits in Granite" (1, pp. 265–291). This stands, because the order probably is controlled by the relative concentrations of cassiterite and wolfram (and molybdenite) in the mineralising fluids; and either cassiterite-wolfram or wolfram-cassiterite predominate, in special cases. 2. Pipe Deposits in Altered Sedimentary and Volcanic Rocks" (1, pp. 291–304), especially lead-zinc ores, although other sulphides—e.g., chalcopyrite-pyrrhotite ores—are involved. The writer is wrong, and Stillwell and Edwards are right.

Originally, in the "Pipe Deposits in Altered Sedimentary and Volcanic Rocks" the writer agreed that certain unconventional environments—among them the telescoped cassiterite sheeted zones or networks of narrow fractures, cutting the rhyolite and rhyolite tuff, with specularite in Lander County, Nevada,[4] Taylor Creek, New Mexico,[5] and the Potrillos deposits in Durango, Mexico [6]—were of this class, even when lead-zinc ores were not present. But it was thought that the suggestion "that hypogene cassiterite may have been precipitated, quietly and normally, contemporaneously with sulphide deposited within the upper reaches of the mesothermal zone" (1, p. 302) would hold.*

The writer is convinced now that the pipe deposits all have this special quality, even if the cassiterite-lead-zinc do not show it in some places. This is true of the Isabella mine, Queensland, where—among others—stannite is present.[2]

In the lead-zinc pipe deposits certain fractures may have cassiterite in one part of the deposit. Certainly, in the Tennyson mine, Koorboora, Queensland, most of the tin was cassiterite. In one pipe there was 260 feet maximum in

[1] Blanchard, Roland, Some pipe deposits of eastern Australia: ECON. GEOL., pp. 265–304, 1947.

[2] Stillwell, F. L., Lead-zinc ore from the Isabella mine, Herberton, Queensland: Mineragraphic Rept. No. 378, C.S.I.R.O., Feb., 1948.

[3] Edwards, A. B., Some occurrences of stannite in Australia: Australasian Inst. Min. Metallurgy Proc., March–June, pp. 5–66, 1951.

[4] Knopf, Adolph, Tin ore in northern Lander County, Nevada: U. S. Geol. Survey Bull. 640, pp. 125–138, 1917.

[5] Hill, J. M., The Taylor Creek tin deposits, New Mexico: U. S. Geol. Survey Bull. 725, pp. 347–359, 1921.

[6] Ingalls, W. R., The tin deposits of Durango: Am. Inst. Min. Met. Eng. Trans., vol. 25, pp. 146–163, 1895.

* One period of mineralization only.

depth (1, pp. 296–298). In another—maybe only a few feet or hundreds of feet—there may be stannite. Or they may be together. But stannite *usually* is on top. In the words of Edwards (3, p. 47), "These ores are simply 'telescoped ores' in which cassiterite *normally* (the writer's italics) *preceded* the sulphides. The time interval must, of course, have been short, because no break in the mineralisation process is indicated."

The writer owes Stillwell and Edwards an apology for not having received the technical data from Australia.

ROLAND BLANCHARD.

SIERRA MADRE, CALIF.,
Sept. 17, 1952.

THE DEFORMATION OF BANDED IRONSTONES IN SOUTHERN RHODESIA.

Sir: The paper by Spencer and Percival on Indian Banded Haematite Jaspers (Econ. Geol., June-July 1952, pp 365–384) is an excellent contribution to the literature on these peculiar rocks. They mention occurrences of similar rocks in various parts of the world including South Africa. Under this heading they may or may not have intended to include Southern Rhodesia. However this may be, such rocks, locally called "Banded Ironstones," are common in our Basement Complex. They are commonly much deformed, and I have for some time been collecting information and specimens, with a view toward studying the different types of deformation that they exhibit. Before seeing the Spencer and Percival paper I had already come to the conclusion that more than one kind of deformation had taken place, and the authors have clearly demonstrated that such was the case in India. Broadly speaking, two principal types can be recognized: deformation while the rocks were plastic, and later deformation when they were hard and brittle. In Southern Rhodesia the following types can be seen:

a) Plastic deformation without fracture, producing contortion.
b) Slumped bedding structures.
c) Non-plastic deformation with considerable fracturing.
d) Large scale tectonic fracturing.

Type a has resulted in small scale folding, in places quite tight and intricate, the amplitude of the folds being measurable in inches. No fracturing took place, but the plastic condition at the time of deformation is shown by the packing of the material in the crests of the folds and the thinning of the middle limbs.

Type b is exceedingly rare, and I have only managed to collect one convincing example of slumped bedding. It emphasizes the essentially sedimentary nature of the material. The specimen consists of regularly banded ironstone with the exception of one section about an inch thick in which the fine banding is contorted as in typical slumped sediments. The "way up" can be determined from the specimen.

Type c is associated with later infillings of quartz in the fractures. The thickness of individual bands is not appreciably affected and the rocks were obviously brittle when it took place. The scale of deformation is generally quite small, the fractures are clean, and the portions relatively displaced. Types *a* and *c* can often be seen in the same hand specimen.

Type d affects whole masses of banded ironstone many feet thick, which have been fractured as a unit during tectonic disturbances, and the sections in many places have been considerably displaced among the less resistant schists.

I had intended to make a detailed study of these different kinds of deformation, but the excellent work of Spencer and Percival has demonstrated these features far more clearly than I could have hoped to do, and has reduced my task merely to the writing of this short note. They are to be warmly congratulated.

GEOFFREY BOND

DEPT. OF GEOLOGY,
NATIONAL MUSEUM OF SOUTHERN RHODESIA,
BULAWAYO, S. RHODESIA,
Oct. 15, 1952.

REVIEWS

Troisième Congrès pour L'Avancement des Études de Stratigraphie et de Géologie Carbonifère. Compte Rendu, Tome 1. Heerlen, 25–30 June 1951.

Articles on coal petrography and coal geochemistry by authors whose surnames begin in letters A to K:

ABRAMSKI, C. **Zusammen zwischen Kohlenpetrographie und Verkokung:** pp. 1–4.

DIJKSTRA, S. J. **Some practical applications of coal petrography:** pp. 169–171.

HOFFMANN, E. **Aufgaben, Bedeuten and derseitiger Stand der angewandten Kohlenpetrographie:** pp. 281–287.

KREVELEN, D. W. VAN. **Some chemical aspects of coal genesis and coal structure:** pp. 359–368.

KÜHLWEIN, F. **Kohlenpetrographische Grundlagen der Aufbereitung:** pp. 369–374.

Four of the five articles listed above, taken together, provide an excellent insight into the present status of German coal petrography. Later volumes of the proceedings of this conference, in all probability, will see the publication of similar articles by such German coal petrographers as E. Stach, R. and M. Teichmüller, K. Lehmann, and R. Potonié, and by other European coal petrographers who attended the Congress. The time of appearance of other volumes is uncertain; the articles of the present volume are of sufficient interest to coal geologists to justify immediate comment.

One of the important aspects of coal geology is the study of the physical components of coal in some such way as minerals are studied as the components of sedimentary and igneous rocks. By analogy, likewise, this particular branch of coal geology has commonly been called Coal Petrography or Coal Petrology. There are very few coal geologists in America whose primary interest and chief activity is, or has been, in the field of coal petrography. Microscopic study of coal, or coal microscopy, has been carried on in North America very largely by investigators trained in the science of botany who naturally make coal petrography an objective secondary to the study of the fossil plant material. Such fossil plant material, particularly the plant spores, is coming into greater and greater use in supplying index fossils, useful for the identification and correlation of coal and other beds carrying such fossils.

The practical importance of coal petrography seems to have been better understood on the continent of Europe than in North America. It appears to have been one of the objectives of the scientists who contributed papers on coal petrography to the Heerlen Congress, to acquaint the foreign visiting scientists with the characteristics of their professional activities and with the nature and objectives of coal petrography as it is practiced in western Europe, particularly in Germany, Holland, and France. This has been quite well done in four of the papers listed;

the paper by Dr. van Krevelen concerns certain interpretations relating to the chemistry or geochemistry of coal.

The paper by E. Hoffmann is a relatively condensed statement descriptive of the nature and content of what he regards as coal petrography. This branch of geology he looks upon as a connecting link between geology, mine surveying or geological mapping, beneficiation, and chemistry. Very briefly he shows how, by refined microscopic methods, it is possible for the coal petrographer to assist the preparation engineer in the production of coal of specific and special qualities for particular uses, such as, the production of superquality coal used in the manufacture of electrode coke. But its use in the more routine and more common procedures of blending different coals to produce a product satisfactory for the manufacture of metallurgical coke is not unimportant, as is brought out in the paper by Abramski. Hoffmann includes in coal petrography such rather remotely correlated studies as correlation and identification of coal beds, coal bed mapping, classification, and studies in coal metamorphism, as well as investigations in coal beneficiation, to which studies American coal geologists might be inclined to limit the field of coal petrography. That is to say, Hoffmann includes in his concept of coal petrography almost everything that American geologists place in the broader field of coal geology. It is apparent, however, that a strict subdivision is impossible. Hoffmann's paper is an excellent and succinct account of the nature of coal geology, as the reviewer understands the meaning of the phrase. There are included, short comments on instruments and methods. Reference is made to a recently issued Leitz microscope specially devised as a plant instrument for the study of broken coal in coke works and steel works laboratories. It would be interesting to know how many such instruments are in use. In a comment on this paper Dr. Kühlwein points out that this equipment just referred to would provide excellent service in spore studies.

The paper by Kühlwein is an exposition of the use of coal petrography technique in coal preparation. The procedure is based largely on the variations in the physical properties of the banded ingredients and based upon such differences, means and devices as are set up to effect the segregation or concentration of the individual ingredients in the "prepared" coal. Difference in specific gravity is an important consideration. K. assigns low gravity characteristics below 1.3 to "bitumen-rich clarain and durain"; whereas low-ash vitrain is given as 1.3, impure vitrain and fusain 1.4–1.7, and the average gravity of bone (*Brandschiefer*) is given as 1.7. Assuming that "Brandschiefer" is the German equivalent of what is here called "bone," the criteria for identification of the material is given:

"Bone (*Brandschiefer*) is an impure coaly rock with a specific gravity averaging 1.7, but which varies between 1.5 and 2.0, containing 20–60% by volume of shale or a similar range in the content of ash. These criteria serve for the technical purposes of preparation, coking, and combustion." (Translated.)

In the latter part of his paper Kühlwein gives a number of examples of "applied coal petrography."

S. J. Dykstra of the Geological Bureau, Heerlen, describes the procedure followed by members of his organization in preparing graphic petrographic profiles of coal beds. He recognizes the following components: fusain, durain, pseudocannel (canneloid), impure coal, and clarain. This latter ingredient is regarded as a mixture of vitrain and durain, an opinion which is in accord with common European practice but one which the reviewer regards as erroneous. The chief use of the graphic profile of coal beds and the analytical petrographic summaries derived therefrom seems to be as an aid in the correlation of beds. Dykstra makes a further point, however, relative to the importance of a knowledge of the petro-

graphic composition of coal beds in its bearing on the cause of spontaneous combustion of coal. Because of the presence of characteristic cracks in vitrain this ingredient has greater liability to spontaneous combustion than the other ingredients, according to Dykstra.

To the reviewer it seems probable that the author sacrificed more complete consideration of the usefulness of coal bed profiles to the demands for brevity. Their application to preparation problems might well have been mentioned, among others.

The paper by van Krevelen is an excursion into the rationalization of the chemical structure of coal, the origin of coal, and coal metamorphism. Two lines of argument determine the course of the discussion and the conclusions reached. The first is that peat formation and the processes affecting the accumulated vegetable material, which the geologist would designate as diagenetic, that is, changes prior to burial and hence before geological processes set in, are part of the coalification process; and, second, that the chemical changes in the geological process of coalification from lignite to anthracite can be interpreted by reference to a graph, or series of graphs, in which the ratio of the atomic H/C is plotted against the ratio of atomic O/C.

With respect to the first assumption, which is in accord with statements in many textbooks and other publications, and which is probably the conventional concept with respect to coal genesis, the reviewer believes that the author might profitably have examined the idea that diagenetic processes that modify the character of accumulations of vegetable organisms are primarily destructive rather than preservative, so that if continued a sufficient time they will bring about the complete obliteration of the organisms. The destructive processes may be halted, temporarily or for a long time, in which case coal is not formed, or, if they are buried, from time to time as geological vicissitudes increase in severity, coalification and metamorphism of the coal takes place. There is the additional important consideration that the degree of disintegration suffered by the organic deposits is largely responsible not for the coalification process as such, but for the *type* of coal material formed. Furthermore, it is not necessary to assume that all the products of diagenesis of the vegetable organisms necessarily become transformed into coal. More information is needed to prove that this is the case. The particular reference is to dopplerite. The occurrence of the equivalence of this material in bituminous coal is a matter of controversy.

The loss of cellulose as contrasted with the greater stability of lignin, noted by van Krevelen, appears to the reviewer as possibly a diagenetic phenomenon and not a geological phenomenon taking place after burial. Certainly there is need for botanical opinion whether or not initial cellulosic structures may not be preserved as coal, if the particular tissue had never been subjected to diagenetic disintegration brought about by bacterial and other destructive agencies. Such a condition might exist if essentially fresh uncontaminated wood was immediately ingulfed in sediments from which it was never released.

With respect to the second basis for rationalization, this appears to be essentially a re-expression of the well known increase in carbon content of coal with advancing rank. As rank increases so likewise does the carbon content, and the hydrogen and oxygen decrease in relative amounts. Expressing this relationship on an atomic basis is probably helpful. The diagrams presented by van Krevelen indicate in what part of the coalification procedure the most rapid changes in the amounts of hydrogen and oxygen take place. The reasoning is carried beyond this simplified statement by fairly elaborate interpretations of the changes in terms of

the condensation of cyclic structures. There is probably good chemical evidence for assuming that if condensation is the critical result it might take place along the lines suggested; the reviewer does not claim to be a qualified judge of this point. However, there are so many references to non-existent dubious substances of supposititious reality such as vitrinite, exinite, fusinite, etc., that the argument is considerably vitiated. The statement that a certain conclusion in regard to the origin of fusain "accounts for the occurrence of all kinds of gradual intermediate forms between vitrinite and fusinite" is a case in point. There are, of course, intermediate stages between vitrain and fusain, which are materials representing definite varieties of coal or banded ingredients; but what are "vitrinite" and "fusinite" other than imaginary concepts devised to provide a basis for a pseudo-mineralogy of coal?

The reviewer has hopes that once the geological aspects of coal formation and coal metamorphism are realized, that coal geochemists will come forward with a naturalistic picture of the essential nature of the substance coal, whether it originates from fusain, humic matter, waxy substances, resins, or other plant material, and the nature of the structural changes that take place in this substance as the severity of the geological environment increases. There is a question whether the course of these changes is simply a continuation of the diagenetic alterations.

GILBERT H. CADY.

URBANA, ILLINOIS,
October 3, 1952.

Stepping Stones to the South Pole. By J. R. NICHOL. Pp. 199; figs. 26. Library Publishers, Inc., New York, 1952. Price, $3.75.

This new addition to Antarctic literature brings up to date the account of all the exploration of this intriguing and forbidding region. It includes not only the early expeditions, beginning with the voyage of Diaz in 1487, and continuing through the more renowned ones of Cook, Weddell, d'Urville, Ross, Borchgrevink, but also comprises a highly interesting account of the first aerial conquests of the South Pole by Admiral Byrd and Sir Douglas Mawson.

Mr. Nichol, himself captivated by the great saga of the South Pole, has thoroughly engrossed his reader in the fantastic adventures of men of boundless courage and determination, and has filled his book with many excellent photographs.

Contemporary Ethiopia. By DAVID A. TALBOT. Pp. 267. Philosophical Library, New York, 1952. Price, $4.50.

Ethiopia emerged as a subject for western consideration during her darkest hour. Since Haile Selassie's return to the throne there has been little thought about this ancient land of the Queen of Sheba and still less written. This book has been written with the hope of shedding some much-needed light on this all too-neglected country. David Talbot, an American journalist, who came to Ethiopia seven years ago and has since been editor of the Imperial Government English publications and of the Ethiopian Herald, seems highly qualified to write this book. His official position has gained him access to authoritative data on the country's economic and political condition and his interest, intelligence and sensitivity have gained him insight into the sociologic aspects of this rich and ancient civilization.

Ethiopia is the oldest country on the African continent and as such has had a long and varied history. The author is more concerned, however, with Ethiopia's history of the last century and particularly with the Ethiopia of the last few decades. His principal aim is to present to the western public the Ethiopia of

today as she has developed, since the Fascist occupation, under the capable hands of her Emperor who has built "a modern state on the ramparts of the old." The Fascist occupation, although it crushed Ethiopia's spirit, served as a training period for her eventual liberation. Commerce and industry were revitalized under Italian rule and despite the damage to Ethiopia during the war, the impetus given by the Italians, plus the considerable material and technologic advances they left behind, has largely awakened Ethiopia to her economic potentialities and has continued her in her progress. Now, in an ordered but free country, bridges, roads, factories have been built and nothing can be more telling than the figures of Ethiopian trade. In the 1930's it was valued at approximately $8,000,000; in 1943, two years after the return of Haile Selassie it increased to $22,000,000 and between 1945–49 it had reached $54,000,000. This figure, which is constantly rising, indicates the possibilities of development in this land of yet unexplored wealth. It is known that Ethiopia's resources lie in minerals, rainfall, fertile farm land and timber. ". . . the enormous potential of this almost virgin land [is] awaiting the skills of modern technique to make [its] blessings available for the use of mankind."

In addition to such pertinent information as mineral and agricultural resources, the author also gives very illuminating accounts of the financial, political and communications organization of the country. Highly valuable also are the chapters dealing with the social, religious and economic habits of the people: racial and character traits, marriage, religion, education, farming methods, law, etc. What is highly admirable about this book is that never once does the author sound patronizing when discussing mores different from his own. One rather feels a real contact between the writer and the civilization he describes.

The book is a highly successful survey into a fascinating and promising country that provides the reader with valuable information and inspires his interest in this little known land.

B. A. BROMBERT

NEW HAVEN, CONN.,
November 1, 1952.

Erzmikroskopisches Praktikum. By HANS SCHNEIDERHÖHN. Pp. 284; pls. 32; figs. 113; tables 39. E. Schweizerbart'sche Verlag., Stuttgart, 1952. Price, DM 40.60.

This new volume by the well-known author of mineralography is prepared in the careful, precise style of the author's former writings. It commences with the chronological development of the use of the ore microscope. There follows twelve parts: I, Erzmikroskopische Apparaturen, in which is given an historical review of the use of the ore microscope and details of the theory and use of the microscope, camera and supplementary equipment; II, Die Anfertigung von Erzanschliffen, deals with the making of polished specimens; III, Optische Untersuchungsmethoden, is a very detailed section in optical properties and their determination. The contents of the other parts are indicated by their titles, namely, IV, Erzmikropische Beobachtungen über Kohäsion, electrische und magnetische Eigenschaften; V, Chemische Reaktionen an Erzanschliffen zur Diagnose der Erzmineralein; VI, Mikrochemische, spektrographische und röntgenographische Bestimmung von Erzmineralein; VII, Verfahren zur Entwicklung des Erzefuges ("Strukturätzung"); VIII, Kornmessungen und Mengenmessungen im Erzmikroskop; IX, Lagebestimmungen von Erzmineralein im Anschliff; X, Übersicht über die Forschungsgegenstände und Forschungsaufgaben der Erzmikroskopie; XI, Beobachtungen am Ein-

zelmineral; XII, Das Gefüge der Aggregate. Part XII, deals concisely with the textures and structures of the ore minerals and is beautifully illustrated by 32 choice plates. In a pocket is a folded pamphlet of 24 tables designed to trace the minerals on the basis of properties to the descriptions in Schneiderhöhn's Erzmikroskopisches Praktikum.

The volume covers very thoroughly the contents as indicated in the respective parts and should prove a valuable addition to the literature on the ore microscope and its use.

BOOKS RECEIVED.

FRANK G. LESURE.

U. S. Geological Survey—Washington, D. C., 1952.

Prof. Paper 218. Geology and Mineral Resources of the Hardin and Brussels Quadrangles (in Illinois). WILLIAM W. RUBEY. Pp. 179; pls. 21; figs. 17. Price, $2.25. *Mineral resources include limestone, cement materials, one coal bed, and sand and gravel.*

Prof. Paper 233-C. Upper Silurian Brachiopods from Southeastern Alaska. EDWIN KIRK AND THOMAN W. AMSDEN. Pp. 53–66; pls. 4; figs. 6. Price, 55 cents.

Prof. Paper 234-A and 234-B. Ostracoda from Wells in North Carolina. FREDERICK M. SWAIN. **Part 1, Cenozoic Ostracoda.** Pp. 58; pls. 7; figs. 3. Price, 75 cents. **Part 2, Mesozoic Ostracoda.** Pp. 59–93; pls. 2; figs. 4. Price, 40 cents. *Descriptions, illustrations, geographic distributions, and stratigraphic ranges of 45 Mesozoic and 32 Cenozoic Ostracoda species.*

Prof. Paper 241. Vicksburg (Oligocene) Smaller Foraminifera from Mississippi. RUTH TODD. Pp. 53; pls. 6. Price, $1.00. *Descriptions and distributions of 176 species.*

Prof. Paper 243-B. Tertiary Stratigraphy of South Carolina. C. WYTHE COOKE AND F. STEARNS MACNEIL. Pp. 19–29; fig. 1. Price, 15 cents. *Revised classification based on new stratigraphic and paleontologic information.*

Bull. 972. Geology of the Canyon Ferry Quadrangle, Montana. JOHN B. MERTIE, JR., RICHARD P. FISCHER, AND S. WARREN HOBBS. Pp. 97; pls. 2; figs. 3. Price, 75 cents. *Includes short history of early placer mining in the area.*

Bull. 973-B. The Coalwood Coal Field Powder River County Montana. ROBERT P. BRYSON. Pp. 23–106; pls. 12; figs. 12; tbls. 6. Price, $3.25 (Buckram). *Reserves include 1,600 million tons of lignite to subbituminous C coal in beds 30 or more inches thick.*

Bull. 974-E. The Eastern Front of the Bitterroot Range Montana. CLYDE P. ROSS. Pp. 135–175; pl. 1; figs. 14. Price, $1.00. *Author concludes that gneiss bordering Idaho batholith resembles sedimentary rather than igneous rock, both in general aspect and in details of texture and composition.*

Bull. 975-B. Geology of the Quicksilver Deposits of Canoas, Zacatecas, Mexico. DAVID GALLAGHER. Pp. 47–85; pls. 5; figs. 2; tbls. 2. Price, $1.00. *Cinnabar occurs in Stockworks in major zones of fracturing at top of latite dome.*

Bull. 979-B. Manganese Deposits of Southeastern Utah. Manganese Deposits of Utah, Part 2. A. A. BAKER, D. C. DUNCAN, AND C. B. HUNT. Pp. 63–157; pls. 2; figs. 21. Price, 60 cents. *About 500,000 tons of low-grade manganese ore occurring mainly in stratified deposits. Ore dominantly pyrolusite with some psilomelane and manganite.*

Bull. 982-A. Phosphate Rocks in the Deer Creek-Wells Canyon Area, Idaho. WAYNE RUSSELL LOWELL. Pp. 52; pls. 3; figs. 18; tbls. 5. Price, 45 cents. *Petrographic study indicates phosphate rock may be chemical precipitate.*

Bull. 983. Corundum Deposits of Montana. STEPHEN E. CLABAUGH. Pp. 100; pls. 6; figs. 13. Price, $1.75. *Description of occurrences of gem and industrial sapphires in igneous dikes and placer deposits. Sapphires believed product of direct crystallization from magma. Deposits of abrasive corundum attributed to metamorphism of alumin-rich sedimentary rocks.*

Bull. 985. Annotated Bibliography of North American Geology, 1950. MARJORIE HOOKER. Pp. 394. Price, $1.00.

Bull. 988-A. Geology of the Uravan Mineral Belt. R. P. FISCHER AND L. S. HILPERT. Pp. 13; pls. 3; figs. 5. Price, 35 cents.

Bull. 988-B. Geologic Guides to Prospecting for Carnotite Deposits on Colorado Plateau. DORIS BLACKMAN WEIR. Pp. 15–27; figs. 9. Price, 15 cents.

Bull. 991-A. Geophysical Abstracts 148, January–March 1952. MARY C. RABBITT AND S. T. VESSELOWSKY. Pp. 73. Price, 25 cents. *Abstracts Nos. 13284–13547.*

Bull. 991-B. Geophysical Abstracts 149, April–June 1952. MARY C. RABBITT AND S. T. VESSELOWSKY. Pp. 75–143. Price, 25 cents. *Abstracts Nos. 13548–13802.*

Surface Water Supply of The United States. 1949, Parts 1, 12, and 13. 1950, Parts 5, 7, 8, 9, 10, and 11.

Circ. 186. Pitchblende Deposits at the Wood and Calhoun Mines Central City Mining District, Gilpin County, Colorado. F. B. MOORE AND C. R. BUTLER. Pp. 8; pls. 3; figs. 2; tbls. 2.

Circ. 189. Uranium Occurrences on Merry Widow Claim White Signal District, Grant County, N. Mex. Pp. 16; pls. 2; figs. 3; tbls. 2.

Circ. 194. A Glossary of Uranium- and Thorium-Bearing Minerals, 2nd Edit. JUDITH WEISS FRONDEL AND MICHAEL FLEISCHER. Pp. 25.

Circ. 195. Radioactivity of Selected Rocks and Placer Concentrates from Northeastern Alaska. MAX G. WHITE. Pp. 12; figs. 5; tbls. 4.

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1951.

Rmo-904. Progress Report on Gamma-Ray Logging Activities. SHERMAN S. COMSTOCK. Pp. 37; pls. 8.

U. S. Bureau of Mines—Washington, D. C., 1952.

Mineral Trade Notes, Vol. 35, No. 1. COMPILED BY FLORENCE E. HARRIS AND MARY E. TROUGHT. Pp. 50.

National Science Foundation. List of International and Foreign Scientific and Technical Meetings. Pp. 19. *Includes meetings definitely or tentatively scheduled from October 1, 1952 through 1955.*

Petroleum Productive Capacity. Pp 102; figs. 16; tbls. 16. National Petroleum Council, Washington, D. C., 1952. Price, 40 cents. *Study of petroleum industry giving immediate outlook and long-term prospects for petroleum supplies available to the United States.*

California Division of Mines—San Francisco, 1952.

California Journal of Mines and Geology, Vol. 48, No. 4. Pp. 255–387; pl. 1; figs. 4. *Mines and Mineral Resources of Del Norte County, California, by J. C. O'Brien; Mineral Commodities in California during 1950, by Henry H. Symons and Fenelon F. Davis.*

Legal Guide for California Prospectors and Miners. COMPILED BY L. A. NORMAN, JR. Pp. 79; figs. 3.

The Great Eruption of Coseguina, Nicaragua in 1835. HOWELL WILLIAMS. Pp. 45; figs. 7; tbls. 2. University of California Press, Berkeley and Los Angeles, 1952. *Historic eruption believed caused by sudden ultravesiculation of magma.*

Indiana Geological Survey—Bloomington, 1952.

Bull. 7. Industrial Sands of the Indiana Dunes. C. L. BIEBER AND NED M. SMITH. Pp. 31; pls. 6. Price, $1.00. *Discussion of geology, economic utilization, conservation and reserves of industrial sand deposits south of Lake Michigan.*

Kansas University and Geological Survey—Lawrence, 1952.

Bull. 97. Oil and Gas Developments in Kansas during 1951. W. A. VER WIEBE, J. M. JEWETT, E. D. GOEBEL, AND A. L. HORNBAKER. Pp. 188; pls. 2; figs. 15; tbls. 67. *Production and exploration information.*

Missouri Geological Survey and Water Resources—Rolla, 1952.

Circ. 8. Geologic Section of Pennsylvanian Rocks Exposed in the Kansas City Area. FRANK C. GREENE AND WALLACE B. HOWE. Pp. 19. *Includes graphic section of exposed stratigraphic sequence in vicinity of Kansas City, Missouri.*

North Dakota Geological Survey—Grand Forks, 1952.

Bull. 26. The Geology of Emmons County North Dakota. STANLEY P. FISHER. Pp. 47; pls. 6; figs. 5; tbls. 2.

Bull. 27. Subsurface Geology of South-Central North Dakota. DONALD TOWSE. Pp. 23; figs. 4; tbls. 3.

Preliminary Geologic Map of North Dakota. *Scale, 1:1,000,000.*

Circ. 5. Well Data and Tops of Significant Wells. Pp. 39.

Manitoba Department of Mines and Natural Resources—Winnipeg, 1952.

Pub. 51-6. Ordovician Geology of Lake Winnipeg and Adjacent Areas. ANDREW D. BAILLIE. Pp. 64; pl. 1; figs. 4.

Nova Scotia Dpartment of Mines—Crystal Cliffs, 1951.

Conference on Industrial Minerals. Pp. 129. *Nine papers on importance and resources of industrial minerals in Nova Scotia including gypsum and anhydrite, lightweight aggregates and coal.*

Quebec Department of Mines—Quebec, 1952.

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University of Adelaide—Adelaide, 1952.

Sir Douglas Mawson Anniversary Volume. M. F. GLAESSNER AND E. A. RUDD, EDITORS. Pp. 224. *Sixteen papers of general interest on petrology, minerology, structural geology and stratigraphy by outstanding Australian authors. Economic papers include talc deposits and thermal metamorphism in coal seams.*

Institut Royal Colonial Belge Section des Sciences Naturelles et Medicales—Bruxelles, 1952.

Mém. Tome XX, fasc. 5 et dernier. Contribution à la connaissance pétrographique et géologique de la partie occidentale du Bas-Uélé (Congo Belge) et à la métallogénie des gisements aurifères de cette région. B. ADERCA. Pp. 28; pls. 6; figs. 2. Price, Fr. 80.

Comité Spécial du Katanga—Elizabethville, 1950.

Comptes rendus des travaux du Congrès Scientifique. Contribution à la Connaissance Géologique des Gisements Stannifères Kibariens et à leur Métallogénie. B. ADERCA. Pp. 32; pls. 3; figs. 15.

Boletim do Instituto Nacional de Tecnologia—Rio de Janeiro.

No. 3, May 1951. Pp. 50, figs. 12.

No. 4, Sept. 1951. Pp. 46; figs. 12.

Universidad de Chile Instituto de Geologia—Santiago, 1950.

Publ. No. 1. Geologia des Distrito Minero de la Higuera Ubicado en la Provincia de Coquimbo. JORGE MUNOZ CRISTI. Pp. 107; pls. 11; tbls. 3. *Detailed description of many veins of copper ore in region.*

Gouvernement Général de l'Afrique Equatoriale Française—Paris, 1950.

Notice explicative sur la Feuille Makokou-Est. N. CHOCHINE. Pp. 16. *Reconnaissance map, 1: 500,000.*

Notice Explicative sur la Feuille Port-Gentil—Ouest. V. HOURCQ ET J.-P. DÉVIGNE. Pp. 24. *Reconnaissance map, 1: 500,000.*

Northern Rhodesia Water Development and Irrigation Department—Lusaka, 1952.

Annual Report for the Year 1951. Pp. 10. Price, 1s.

A Geologia do Baixo Mondego nos Arredores de Coimbra. S. SOARES DE CARVALHO. Pp. 36; pls. 2. Coimbra, 1951.

Geological Survey of Taiwan—Taipei, 1951.

Bull. 3. Pp. 72; figs. 3. *Geology of the Chialo Coal Field, Sinchu, Taiwan, by C. S. Ho and T. L. Hsu; The "Sansa Overthrust" and the Related Geologic Structures, by Li-Sho Chang; On the River Capture of Hualienchi, by T. L. Hsu and Pei-Yuan Chen; The Discovery of Fusuline Limestone in the Metamorphic Complex of Taiwan, by T. P. Yen, C. C. Sheng and W. P. Keng.*

Régence de Tunis Direction des Travaux Publics—Tunis, 1952.

Annales des Mines et de la Géologie No. 9. Les Gîtes Plombo-Zincifères de Tunisie. PAUL SAINFELD. Pp. 265; pls. 7; figs. 60; tbls. 4. *Detailed description of 60 lead-zinc deposits.*

SCIENTIFIC NOTES AND NEWS

Correction: Issue no. 6 carried an item reading: "Andrew C. Lawson, Professor emeritus of the University of California, died at his home at the age of 90 years on June 16." A typographical error stated the name to be Larson.

ELY MENCHER, formerly Senior Field Geologist and Research Geologist with the Socony Vacuum Oil Company of Venezuela, has been appointed as Associate Professor of Geology in the Department of Geology and Geophysics at the Massachusetts Institute of Technology. Dr. Mencher will conduct courses in Stratigraphy and Petroleum Geology and will continue his research on the Geology of South America.

THE NEW MEXICO GEOLOGICAL SOCIETY had its third annual field conference on October 5th in the Rio Grande country. There were 230 geologists in the party.

THE DEPARTMENT OF GEOLOGY at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY has been renamed the DEPARTMENT OF GEOLOGY AND GEOPHYSICS to recognize increased emphasis on instruction and research in geophysics within the department and will now offer two separate courses, one leading to the degree of bachelor of science in geology and the other to the degree of bachelor of science in geophysics. Either course satisfies the requirements for admission to the M.I.T. Graduate School for work toward advanced degrees in geology, geophysics and geochemistry.

J. J. O'NEILL, who recently retired as Vice-Principal of McGill University, has been designated an Honorary Life Member of the McGill Graduates Society.

THOMAS P. ANDERSON, mining engineer and geologist, has resigned from the Raw Materials Division of the U. S. Atomic Energy Commission where he was assistant chief of the Denver Exploration Branch. He will enter private practice in Golden, Colorado.

JAMES E. ATKINSON, consulting mining engineer and geologist, left New York for Columbia, S. A., as general manager for Cia Minera Choco-Pacifico, S. A., operating five dredges in gold and platinum on the Pacific coast of Columbia.

RALPH C. HOMER, formerly teaching at the Colorado School of Mines, has joined the exploration staff of Kennecott Copper Corporation, New York City as chief geophysicist.

JAMES B. SCOTT has resigned his position with the U. S. Geological Survey at Grand Junction, Colorado, to become division geologist with the Oregon State Highway Department in Bend, Oregon.

JOHN S. WINSTON, metallurgist, and LON S. MCGIRK, JR., geologist have been appointed to the staff of the Mackay School of Mines, University of Nevada, to replace Professors Gianella and Palmer who retired this summer. Dr. McGirk, a graduate of Oregon State College and Stanford University has had varied professional experience, having been with the Texas Gulf Sulphur Company and the U. S. Geological Survey. Professor Winston, has taught metallurgy at Illinois

Institute of Technology, the University of Chicago, the Biarritz American University, Valparaiso University and the Missouri School of Mines.

S. G. LASKY, who was on full-time loan from the Department of the Interior to the Paley Commission as special consultant, has been designated as the representative of the Secretary of the Interior on the Interdepartmental Stockpile Committee of the Munitions Board.

H. F. GRACE has succeeded W. A. POPE, retired, as general manager of Nchanga Consolidated Copper Mines, Northern Rhodesia, Africa. H. E. NELEMS, manager of Rhokana Corporation, Ltd. N.R., will succeed Mr. Grace as Manager of Nchanga, while L. W. ALLEN, assistant manager at Nchanga, will become manager of Rhokana.

WALTER E. SEIBERT, JR. has resigned as resident geologist at Reynolds Mining Corporation bauxite operations in Alexander, Ark. He is now assistant to the president of St. Lawrence Corporation of Newfoundland and associated operations.

FRANK E. JOHNSON, Washington, D. C., has been appointed deputy administrator of the Defense Minerals Exploration Administration.

J. FRANK SHARP has been appointed chief geologist of the Consolidated Coppermines Corporation with headquarters at Kimberly.

ALAN T. BRODERICK, formerly with the M. A. Hanna Company as regional geologist, is now chief geologist with the Inland Steel Company, Iron River, Michigan.

JOHN W. SVANHOLM has resigned as assistant chief engineer and geologist for the Haussermann interests (Benguet Consolidated Mining Company, Balatoc Mining Company and Consolidated Mines), in the Philippines. Mr. Svanholm is establishing a practice in Venezuela as consultant engineer and geologist.

TEIICHI KOBAYASHI, Professor at the University of Tokyo, on his return from the International Geological Congress in Algiers, has been visiting eastern universities and gave a lecture before the Geological Club of Yale University on November 17th.

PROFESSOR FREDERICK H. STEWART of the University of Durham, England, was the recipient of the Mineralogical Society award at the annual luncheon meeting held in Boston on November 14th. Earlier he gave a lecture at Yale University on the "British Permian Evaporites."

EMMONS MEMORIAL FELLOWSHIP

The S. F. Emmons Memorial Fellowship in Economic Geology is available for the academic year 1953–54, with a stipend of $1,500.00. Applications and accompanying testamonials should be submitted not later than February 15, 1953.

Applicants should be qualified by training and experience to investigate some problems in Economic Geology and should submit a definite statement of the problem to the Committee, under whose supervision the work may be undertaken at any institution approved by them. The Fellow must give entire time to the problem, which may be used for a doctoral dissertation. Application blanks may be obtained from Alan M. Bateman, Yale University, H. E. McKinstry, Harvard University, Paul F. Kerr, Columbia University, or the Secretary, Columbia University.

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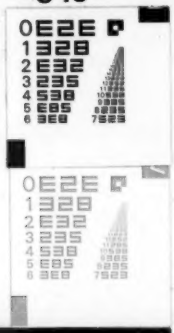
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